Technological Revolution in Industrial Ecology

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Energy Transition

Economic, Social and Environmental Dimensions

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Industrial Ecology

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Industrial ecology and circular economy is a peer-reviewed book series that focuses on different disciplinary approaches to waste management, sustainable practices & strategies on different scientific, societal, pyschological, technological, economic, governance, and cultural and political aspects of the ongoing and emerging debate. This primary goal of this series is to offer scientists from different school of thoughts and institutions a platform for scientific analysis and debate.

Undeniably, Industrial ecology is a rapidly growing field that systematically examines local, regional and global materials and energy uses and flows in products, processes, industrial sectors and economies. It focuses on the potential role of industry in reducing environmental burdens throughout the product life cycle from the extraction of raw materials, to the production of goods, to the use of those goods and to the management of the resulting wastes. Industrial ecology is ecological in that it (1) places human activity—industry in the very broadest sense—in the larger context of the biophysical environment from which we obtain resources and into which we place our wastes, and (2) looks to the natural world for models of highly efficient use of resources, energy and byproducts. By selectively applying these models, the environmental performance of industry can be improved. Industrial ecology sees corporate entities as key players in the protection of the environment, particularly where technological innovation is an avenue for environmental improvement. As repositories of technological expertise in our society, corporations provide crucial leverage in attacking environmental problems through product and process design.

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Technological Revolution in Industrial Ecology

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Abstract *Industrial Ecology* (IE) is a field that is engrossed in the production stages, including products and services for protecting, recycling, and reusing natural resources. It is more like a natural eco-system that includes all processes and phases of resource extraction to conversion into finished products or services. The concept of industrial ecology was first proposed and used by Robert Frosch and Nicholas E. Gallopulos in 1989. The idea of 'industrial ecology' flourished with the emergence and recognition of the industrial revolution that transformed the whole agriculture and handicraft industry into a large-scale efficient and effective manufacturing industry. Overall, it can be said that the industrial revolution is the part of the industrial restriction, has become possible due to the resurgence of the technology in entire industrial productions and operations around the globe. With time, scientific revolutions are characterized by the advancement of product and process innovation intended for cost-effective policies and processes. Moreover, constant industrial revolution and progress created an adverse effect on the environment due to poor mechanisms of waste disposal and resources depletion. This study intends to explore and understand the role of the technological revolution in creating industrial ecology. Additionally, this study deepened knowledge with the recent trends and fashion to adopt emerging technological tools; (artificial intelligence, big data analytics, and blockchain technology) to sustain organizational/business productivity. These evolving tools help the organization design efficient processes like cost reduction and revenue generation. Therefore, inquiry provides practical guidelines to industrialists, policymakers,

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practitioners, and regulatory bodies to adopt the emerging machinery and embed it in the whole organizational infrastructure system and set-ups to gain sustainable competitive outputs.

Keywords Industrial ecology · Blockchain technology · Artificial intelligence · Big data analytics · Energy

1 Industrial Ecology

Industrial ecology (IE) is concerned with the flow, energy usage, and material used in the industrial setup. The industrial ecosystem is formed by humans, imitating the natural ecosystem, where the leftover phase may be used. Industrial ecology is more like a natural ecosystem and swaps from a linear to cyclical loop system and seems unstable, just like the natural ecosystem. Universally, the industrial economy is exhibited as a grid that begins extracting resources from the earth and molding them into finished products that may be traded to meet human requirements (Ayres and Ayres 1996). The whole scenario is processed by engaging the industrial functioning through quantifying the material flows and drafting all the processes. The environmentalists are more often worried about the flow of industrial processes that are becoming trouble for the environment by misusing natural resources and poor waste disposals.

Industrial ecology is an emerging field that includes different dimensions, i.e., engineering, sociology, biology, other natural sciences, etc. The production processes of goods and services are being focused on from the natural viewpoint. They are the fundamental simulation of maintaining and sustaining the natural resources, particularly the industrial ecology (Chertow 2008).

The concept was provoked by considering the natural setup that has supported in identifying and following the scheme of sustainable industrial structure (Erkman 1997). Industrial ecology was propagated in 1989 through scientific research by Robert Frosch and Nicholas E. Gallopulos. This is based upon the doctrines of social and technological systems confined in the biospheres and do not move beyond it. The ecosystem is reflected through observing the natural scenarios in reusing and recycling the materials. Some examples of industrial ecology include:

- Coal-burning process stand-ins the fly ash as a side effect for cement in concrete production.
- Converting the grease or cooking oil into fuel-based vehicles by utilizing second-generation biofuels.
- National cleaner production center of South Africa was established to promote materials produced in the industries of that region. Reduced energy costs and improved waste management are the sustainable means to transform companies into industrial ecology.

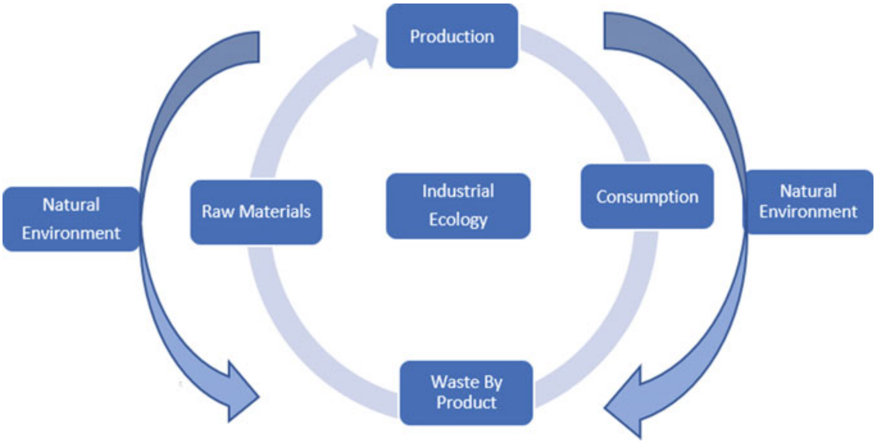

Fig. 1 Industrial ecology (Erkman 1997)

Industrial ecology was established to identify the industrial effects on the environment. IE is still being used globally to set up the industrial systems aligned in such a manner to use lesser natural resources and to utilize the waste material in new ways rather than wasting or spoiling them. Figure 1 elucidates the industrial ecology cycle.

There are few benefits to industrial ecology i.e.

- Cost edge in purchasing material, charges against licenses, waste disposal charges, etc.
- Enhanced environmental protection
- Selling waste and income generation
- Improved corporate image
- Liaison with other industries
- Availing market edge.

Major limitations to industrial ecology are:

- Poor market for materials
- Lack of governmental and industrial support
- Less concern to invest in technology
- Perceived legal implication
- Unwillingness to move to another supplier.

Whether digital or physical eco-parks, both are gaining significance from the industrial masses within this dynamic era. The agreements are being made to deliver and promote the waste to each other inside the projection of ecological business movement. Physical eco-parks are positioned at the identical web page; however, because of the excessive expenses and moving blessings, the eco-parks are commonly digital (Graedel 1996).

1.1 Main Attributes

Industrial concerns begin with the extraction of resources to process, and product disposal has negating effects on the environment (Ehrenfeld and Gertler 1997). The main concern of industrial ecology is to overcome the environmental stress that arises due to industry, promoting innovation, resource effectiveness and sustained growth. Industrial ecology attributes to industrial operations and expands in a supportive ecological manner thus, putting less burden on the planet (Lowe and Evans 1995).

It exhibits industrial regions as a part of a broader environment through a self-contained entity.

The industry is associated with nature throughout the ecological domain and uses the wastes and yields of other industries as their raw products for further processing. Industrial ecology covers two main streams one is related to industrial management, and the other covers the technology side by focusing on the sustainable aspects (Frosch 1992; Jelinski et al. 1992).

The main doctrines of industrial ecology (Tibbs 1992) are as follows:

- Develop an industrial bio-network by considering waste as a resource and collaborating with other industries to utilize their wastes as an input.
- Generating a balance between input and output to natural standards by managing the bridge between industry and environment to enhance awareness regarding ecological behavior, ensuring the time and capacity span of linking the natural ecosystems and confine to the process within the boundaries.
- Reutilizing more environmentally supportive procedures and seeking efficient industrial processes.
- Energy utilization in environment supportive manner.
- Aligning the policies following the supportive ecological concerns.

2 Technological Revolution

"Technology" is derived from techne, meaning art or craft. The Industrial Revolution changes human lives, production, and other resources by bringing technical innovation to industries (Corrado and Hulten 2010; Khan et al. 2021a; Yu et al. 2021). The technological revolution, a sense of ever-quickening change, began much earlier than the eighteenth century and has continued today. Perhaps what was most unique about the Industrial Revolution was its merger of technology with industry. Essential inventions and innovations served to shape virtually existing segments of human activity along industrial lines, creating countless new industries (Brownsword 2008; Khan et al. 2022). The rapid changes in technology started before the eighteenth century and have continued. Every existing sector of human activity along the industrial line has essential inventions and modernizations (Feki et al. 2013; Khan et al. 2021b).

In the nineteenth century, skill upheavals were known as the industrial revolution; 1950–1960 was the age of the scientific-technical revolution, Neolithic revolution, the Digital Revolution, etc. Frequently, the idea of the "technology revolution" has been overused. As a result, it is not easy to study which revolution was vital for human activity and the universe, science, industry, transport, etc. (Heid 1997).

Each revolution includes the following appliances for growth:

- New cheap inputs
- New products
- New processes.

Every single revolution develops something economical—for instance, iron steam engines, which led to the production of Iron railways. For the improvement of the web, advanced and cheap microelectronic tools have been created by mechanical transformation (Idrisov et al. 2018).

Two hundred years ago, the world of technological revolution differed from the periodic waves of technical change that have marked the progress of industrial society—a shift in the socioecological patterns underlying our current sophisticated industrial structure. The importance of measurable goals for invention requires ever-high inputs of capital, energy, and raw material by old standards. On the other hand, the new paradigm identified quality and modification of products and processes. In this era of evolution, steam engines and coal become energy sources. Generally, this technology revolution brings out fear about new activities and employments.

Due to the Industrial Revolution, the quality of life and income level have improved worldwide. Nowadays, the ecosphere has become a digital world like ordering online transport services, booking trains, flights, purchasing goods, etc. Technological inventions will bring competence and productivity in the upcoming days. Transport and communication services will reduce day by day, improving economic growth—the scientific revolution impacts human life, patterns, and lifestyles (Franke 1987). The usage of information technology increases day by day. The advanced technology changed laborers' old equipment, which improved the production and conventional mechanism. Yielded manufacturing designs have been changed into contemporary technology. As the result of this innovation bring improvement in market position.

The living standards of people have been promoted by information technology. Different online services like online shopping video call, online booking of bus, cab, flights are all included in people's lives and enlarge the scope of social connectivity. The most important thing is that the usage of statistics technology increased E-learning rather than the traditional way. E-learning brings out learning enhancement in people's living standards (Kortum and Lerner 1998).

3 Industrial Revolution

The Industrial Revolution (IR) has transformed the economies from small-scale factories concerned about agricultural and handicrafts driven setups to the more mechanical and large-scale technology driven industries. Novel machines and novel power sources, and novel techniques in the existing sectors have become more productive and efficient (Shahroom and Hussin 2018). The industrial revolution was the quiet intensive in human history because of the wide-ranging effects on people's life. "Industrial revolution" refers to describe the eighteenth century period of Great Britain, where rapid transformation occurred. The rural agricultural lands transformed into urban and industrialized areas. The continental-wide change in the form of railroads, Cotton gin, electricity, and other developments transformed society (Ashton 1997).

The IR was the shift to novel industrialized practices in Europe and USA in the era between 1760 to almost 1840. The change encompassed going from manual techniques to machines, novel chemical production and iron processes, the enhanced methods of utilizing steam and water force, the advancement in machines' tools, and the well-established factory setup. The industrial revolution led to an exceptionally high rate of the population (Senge et al. 2001). The IR was a turning point in history and has influenced the routine life of almost all individuals in one way or the other. Particularly the average earnings and population showed stable growth. Few researchers have come up with improved living standards for the first time for the general public and western fraternity. Still, few researchers contrarily described that the living standard implicitly improved in the late nineties and early twenties (Berg and Hudson 1992).

In this era, we are on the brink of the Industrial Revolution and on the verge of the technological revolution that has altered the way we live, work, and relate with each other. Considering the scale and scope, the transformation due to technology is quite different from any other human experience, as is evident in the Covid-19 era, where people survived their livelihood because of technology (Umar et al. 2021a). So the industrial revolution and the technological revolution have encompassed almost all aspects of human life universally (Ragulina et al. 2019; Khan et al. 2021a, b, c). The initial industrial revolution transformed the mechanized process, including stream and water forces. Subsequently, it changed the usage of electric points for mass production. Thirdly, it has used information technology for automating production. Now the fourth revolution is standing on the third one through the digital transformation that started in the mid of the previous century and has the fusion of the technologies muddling the physical, digital, and biological domains (Wrigley 2013).

4 Artificial Intelligence

The term artificial intelligence (AI) was introduced in 1956 but got renowned in the current era because of the projection to use more data, algorithms, computing power, and certainly retaining and maintaining more storage. Initially, in the mid of the previous century, AI's concern was to resolve problems and use symbolic methods. Following the symbolic methods, the concern shifted to mimic basic human reasoning. These initial efforts paved the way for formal reasoning efforts and automation that we are using in the present scenario, as evident from the decision support setups and smart technologies intended to support human abilities. It is evident and reinforced through the movies and fiction where robots similar to human beings take over the whole world. Though the AI mechanics are depicted as scary; however, in reality, these technologies are quite smart and have been beneficial in almost all industries, i.e., production units, retail, banks, health care, etc. AI is basically an extension to the computer sciences field concerned with developing smart technologies capable of carrying out tasks that involve human intelligence (Michalski et al. 1983). AI considers diversified approaches that bring change through deep learning techniques in every aspect of the tech industry. AI is a way that enables individuals to rethink and manage the information, analyze the data, seek insights into decision making, and transform every aspect of human life to more convenience. AI is almost everywhere in our surroundings in the form of self-driving cars, drones, virtual assistants, and software that send messages to stakeholders to make investments. In the recent era, enormous progress has been seen in AI through the computing powers, maintaining and dealing with the large volumes of data, using simple software's to fabricate them into novel algorithms that may predict the cultural interests even. Digital technologies are linked to the biological world, and it is becoming a usual practice these days. The engineers, designers, architects, etc., are integrating the computational designs in additive manufacturing, material engineering, and synthetic biology to discover the symbiosis in the microorganisms, human bodies, the products consumed by humans, and the buildings where human beings inhabit.

The effort is to simulate human intelligence through machines and technology. In simple words, we may define AI as "Developing intelligent machines," but it doesn't describe what makes a machine intelligent? This has been addressed in Artificial Intelligence: A Modern Approach, authors Stuart Russell and Peter Norvig fusing the theme focusing on the concerns regarding intelligent agents in machines. So considering it, AI is all about concentrating on the agents that encode and percepts the details from the environment and performs actions. Therefore, the following approaches have been described concerning AI: thinking and acting humanly and rationally. The thinking process is concerned with cognition and reasoning, whereas the acting processes are concerned with behavior. The last few years have triggered the debates regarding environmental issues and reflected from the debates and discussions, public outrage, and awareness programs that have projected the use of new technologies i.e., Artificial intelligence. AI considers a wider range of environmental concerns like conservation of natural resources, protecting wildlife, effective energy management, energy cleaning, managing waste, and controlling pollution. AI seems to be a game-changer in the global economy. It is expected that by 2030 AI will contribute around 15.7 trillion of the global economy that is more than the current output of China and India together. India outputs about a million engineers every year, out of which 20 percent are jobless. AI has the potential to place an unemployed engineer in any industry-based organization if an individual has done a course in AI (Dick 2019).

AI is a science that deals with reasoning with intense research activities in image processing, language processing, machine learning, and robotics, etc. Generally, AI and machine-related learning have been considered black-art techniques because of insufficient evidence that these techniques may support in return of investment. In the same manner, the functioning of the machine learning algorithm is based upon the developer's experiences and choices. Therefore the usage of AI in industrial applications has been considered an achievement. Contrarily, AI is an organized domain inclined to build valid and install various machine learning algorithms aligned with sustainably applying industrial applications. It follows an organized methodology and discipline to furnish the solutions for industrial applications and operates as a bridge linking academic research outcomes in AI to the industrial practitioners (Hamet and Tremblay 2017).

4.1 Importance of AI

AI automates mechanical learning and discovery through data; still, AI is different from robotic automation that is hardware-driven. AI carries out the consistent, sizeable computational task without any exhaustion rather than conducting only manual tasks. Human input is required to run the setup favorably.

AI augments intelligence to the prevailing products. Usually, AI cannot be traded as a complete application in different cases. Instead, the existing products already in use may be enhanced through AI capabilities. A large volume of the data is managed along with automation, discussion platforms, innovative technologies from security intelligence to investment analysis is catered through AI. Enhanced learning algorithms are adapted through AI for programming. AI search structure and consistencies in the data algorithm require the skill. The algorithms are considered as a classifier or a predictor. So AI is more like back promulgation that allows the model to modify itself through added data (Lu et al. 2018).

AI scrutinizes the large and wider data by deep neural networks having multiple layers. Detecting a manipulation within layers was difficult a few years ago. All have transformed with computer power and big data. The deep learning models may better be managed through feeding with accuracy. AI attains unbelievable accuracy through deep neural networks that were almost impossible earlier. Our interactive experiences with Google search and photos are formed with deep learning, and they keep working better and accurately with more usage (He et al. 2019).

AI gets the most out of data. Algorithms are self-learning; therefore, the data becomes intellectual property. Usually, the answers are within the data, and one has to apply AI to dig the answers as the data has gained more significant importance than before, so it may take a competitive edge (Agrawal et al. 2017).

4.2 *Usage of AI*

Almost all industries have intense demand for AI capabilities that address the answers used for legal assistance, patents, notifications regarding risks, medical research, and much more (Davenport and Ronanki, n.d.). Other uses of AI encompasses various fields and sectors.

4.2.1 Health Care

The AI applications may arrange awareness regarding personalized medicines, X-ray, and readings. The personal health care assistants may play the role of life coaches for reminding to take medication, exercise and what to eat or not, etc.

4.2.2 Retailing

AI capabilities include virtual shopping capabilities too that refer to personalized recommendations and trading options. AI applications are becoming a better way for stock management and location layout technology for trading.

4.2.3 Manufacturing

AI analyzes the factory input and output data as it streams from the integrated setups to predict and manage demand and supply balance using the recurrent network through sequencing and maintaining the data.

4.2.4 Banking

In financial institutions/banking sectors, artificial intelligence enhances the speed, accuracy, and effectiveness of individual initiatives/human efforts. In the said sector, AI techniques enable individuals to identify fraudulent transactions and speed up banking operations and mechanisms by automating manual data management tasks.

5 Block Chain Technology

Digital transformation brings the world towards continuous innovative products, new efficiencies, and strong customer relationships mechanism through advanced media tools/social media, IoT (Internet of Things), cloud technology for better business decision making. Blockchain is newly acquainted with digital revolutionization among all other digital tools through sound security, resiliency, and efficiency of systems (Vial 2019).

Blockchain is mainly considered technology introduced and relatable to run the Bitcoin cryptocurrency. To date, Bitcoin is still using blockchain technology behind its financial transaction. A common and absolute ledger is used to record financial transactions and track their business assets efficiently and effectively. As we all know, an *asset* can be categorized as tangible (having a physical presence, can be seen and touched) and intangible (opposite to tangible assets having no physical presence, cannot be seen or touched). However, blockchain technology helps businesses virtually track and trade anything with a specific value (Umar et al. 2021b). Bitcoin is a mostly known decentralized digital currency payment system solely based on public financial dealings and transactions named Blockchain. Bitcoin maintains the currency's value without the control or administration of any regulatory authority or government. Despite it, the financial transactions of bitcoin are increasing day by day.

It is noticeable that business successes and growth depend on the fastest and accurate transition of information. Blockchain is idyllic to provide instant, shared, comprehensive, and translucent information stored on an absolute ledger that is restricted and only accessed by authorized network members. Blockchain technology facilitates tracking orders, related payments, financial records, etc. (Crosby et al. 2016).

As blockchain technology gains prevalence and its application continues to grow in the finance sector, its related activities are especially in cryptocurrencies. The rapid growth in the development of blockchain-based applications and their adoption on a large scale revolutionize the overall financial market even without the involvement of regulatory authority for its security. Back in 2008, the concept of blockchain thought came up with some other advances and digital up-gradation to introduce advanced cryptocurrencies. Every electronic transaction is hooked up to a digital address by following Bitcoin's blockchain technology, and Bitcoin users will digitally sign and transfer rights to different users simultaneously. This digital transaction under the Bitcoin blockchain permits all network participants to verify the validity of the transactions severally. The Bitcoin blockchain is observed, monitored, maintained, and collaboratively managed by a geographically scattered cluster of participants (Angraal et al. 2017; Underwood 2016).

Although, the mechanism and configuration of blockchain technology are seen as extremely complex and technical to understand for a common person. While the basic phenomenon behind the usage of blockchain technology is so simple that it is mainly intended to decentralize data storage to get it free from the control of central actor/authority. The recent surge in and subsequent collapse of the value of Bitcoin drags the attention of researchers, scholars, and practitioners to the blockchain architecture that underpins cryptocurrencies. The above-said challenge highlighted that blockchain technology is far beyond cryptocurrencies. Overall, Blockchain as technology comes up with the potential to revolutionaries the overall business structure (routine transactions). In addition, the applications of Blockchain are not limited to cryptocurrency as it can be possibly applied in various environments and disciplines where various complex and heavy transactions are performed (Zheng et al. 2017).

It is quite interesting that different regulatory authorities, federal agencies, and international bodies are interested in defining proper mechanism/structure to regulate blockchain-related activities, particularly virtual/digital currencies. The continuous widespread application of its relative novelty poses difficulty in identifying the relevant agency to investigate the phenomenon behind the blockchain activity and its application in the true sense. In the current competitive era, innovators in various fields appreciate the benefits of the blockchain technology behind Bitcoin. From medicine to finance, various sectors plan to integrate blockchain technology into their infrastructures to ensure data transparency, security, feasibility, and traceability. Due to its decentralized and independent nature, it presented numerous benefits and opportunities for businesses in different industries across the globe (Ahram et al. 2017; Angraal et al. 2017). The benefits of blockchain technology are mentioned as below;

- **Transparency**: Blockchain technology has the critical feature of being highly transparent for the general public to view its transaction ledger. It allows the business to ensure openness and accountability in its financial activities, leading to customer satisfaction, community-centeredness, and company growth.
- **Efficiency**: Block-chain technology increases process efficiency by removing intermediaries in various ordering, payment, etc. This all happens due to its nature of decentralization as it fastened the financial transaction mechanism across the borders with digital currency by using the P2P system. Business management processes become more efficient with an integrated system of financial records, smart contracts. Efficient and timely delivery, even if revolutionize the whole business structure globally.
- **Security**: Block-chain technology ensures the security of business records as each new transaction is far more secure than other record-keeping systems because each new transaction is encoded and linked with the previous business activity/transaction. The word 'block' reflected that it connected with the computer networks, added it in a ledger, and formed a 'chain.'
- **Traceability**: Each transaction is recorded using blockchain technology with the time, cost, and all related items. It is very easy for the audit team to trace the history of the transaction. It plays a very significant role in tracing and preventing transaction-related-frauds. It also ensures/verifies the authenticity of business assets and their related ownership.

Some other Potential Benefits of Block-chain Technology (BCT) (Cole et al. 2019; Khan et al. 2021a, b, c)

- BCT allows verification of transactions without any dependency on the third party.
- The data structure in blockchain technology cannot be altered and removed.
- This technology uses secure cryptography to protect the data ledgers.
- Mutual consensus of all the ledger participants to decide the transaction/data to record in block.

- Chronological ordering of all business transactions.
- Distributed ledger across each node in the blockchain (participant).
- The decentralized system is recorded and stored in the blocks existing in all the computers participating in the chain. Therefore, there is no chance of data loss and its recoverability.
- There is no chance of duplication of entry or fraud due to the requirement of various consensus for entry validation.
- Option for businesses to pre-set conditions on the blockchain.

The above mentioned benefits are explained by Biswas and Muthukkumarasamy (2016) and Chen et al. (2018).

Summing up the benefits of blockchain technology, it has been identified that people associated blockchain technology with the cryptocurrency Bitcoin. Yes, it is a fact that the widespread success and growth of Bitcoin highlighted its importance, but Bitcoin is just one major and prominent example of blockchain application. There are so many sectors that can benefit from applying blockchain technology in their infrastructure by reducing their costs and strong accountability mechanism.

5.1 Blockchain Technology and Industrial Ecology

In this highly competitive globalized era, technological advancements pose the fast-paced economy's challenges towards sustainable competitive practices. The concept of industrial ecology began in 1989, referred to as 'manufacturing strategies.' Industrial ecology is multidisciplinary discourse (based on a specific system) that puts entire effort into understanding the emergent behavior of highly complex integrated systems, and either can be human/natural/technological. This definition presented an essential aspect that it is a comprehensive and complex phenomenon that covers a variety of disciplines such as technical, sociological, philosophy, financial, economic, environmental, and many more. It gives us an entire paradigm shift, including principles and tools that facilitate the industry and policymakers for decision-based activities (Deutz and Ioppolo 2015). As per the theoretical foundations of ecological modernization, technological advancements put the way forward to decouple environmental degradation and economic growth. Technological advancement includes upgrading the mechanism/structure of production, information, and social technologies. These technologies guide the pathway towards developing current and future processes related to additive manufacturing, micro-factories, nanotechnology, the Internet of Things (IoT), self-driving vehicles, sharing economies, and blockchain technology. These all mentioned technologies are very important and have strong implications for environmental and organizational sustainability (specifically supply chain) (Saavedra et al. 2018).

Blockchain technology is considered a developing technology with continuous and rapid growth. The most interesting fact about blockchain technology is that it got popularity in almost all the states, countries, sectors, industries to include it in infrastructure for the most efficient and accurate data management. It is characterized as decentralized databases (ledgers) that are highly secure, auditable, traceable, and maintained on the peer-to-peer network.

As discussed above, blockchain technology comes up with various important avenues for fair, efficient, and effective data usage and its management. Extensively, this technology is also named 'decentralized ledger,' allowing and involving unspecified people to the network for the fair use of data in a highly decentralized manner, free of control standards/mechanism from any regulatory authority or central state.

Overall, it is found that blockchain plays a significant role in our lives by connecting technologies such as artificial intelligence, IoT, and big data with our daily lives. The sound contribution of blockchain technology put forward the virtual ecosystem in the form of three specific viewpoints of data regarding its ownership, transactions, and storage.

Blockchain is a new and emerging technology for collecting, storage, transformation to different points. Here, it is important to understand that the data is held/stored at one place and point, and later on, the data is spread over to unlimited points throughout the network developed for it. This all data distribution process on the blockchain is solely based on the decentralization principle, and supply chain intermediaries between members can be eliminated at any point in time. Therefore, there is no need for a bank or financial institution as an intermediary; buyer and seller can directly carry out the transaction (Andoni et al. 2019).

5.2 Blockchain Potential for Environmental Sustainability

From the last few decades, blockchain technology has been applied to several projects to address the numerous global challenges, including voting and identity to health. Regarding the environmental sustainability domain, 65 initiatives (concept or pilot stage) were taken using blockchain technology (Herweijer et al. 2018). In contrast, a lot of work is needed to mature the usage of blockchain's ability to address environmental concerns at a wider stage and scope. One of the critical features of blockchain highlighted it has sound potential to support environmental sustainability by providing a demonstrable record of all transactions, activities, relative functions, and processes. It includes records of exchange between parties, stipulated time frame, quantity, and mechanism.

Chapron's (2017) highlighted the significance of blockchain technology to address various challenges related to environmental sustainability. Blockchain support for ecological sustainability includes three underlying mechanisms/dimensions: resource rights, product origins, and behavioral incentives (Saavedra et al. 2018). It is noticeable that challenges arise due to the lack of trust and confidence in governing bodies and authorities to use natural resources and maintain ecosystem services. Blockchain technology will help the regulatory authorities/governing bodies on state and federal levels store and provide transparent, reliable, and verified records through a sound digitalization network

(Umar et al. 2021a, b, c). It also can help and facilitate the stakeholders by reducing costs and ensuring transparent/efficient environmental governance (Yu et al. 2021). But before going for the said potential, it must be consciously noted whether blockchain is a public and permitted network to restrict access to only verified parties. This characteristic has substantial implications for those central entities/power dynamics to disrupt existing systems and structures (Zheng et al. 2018). Figure 2 indicates Blockchain usage to attain environmental sustainability.

To make blockchain technology effective for environmental sustainability, stakeholders need to work together and avoid or minimize the limitation/challenges by using the specific mechanism/structure relating to resource rights, product origins, and behavioral incentives (Underwood 2016). The above-suggested mechanism will strengthen the success rate of applying blockchain technology not only for environmental sustainability but also for valuable social outcomes. To create sustainable environmental outcomes through blockchain technology;

- Government should invest in building and strengthening the digital infrastructure in the form of quality hardware for the internet, bandwidth, and, most preferably, digital education to increase participation in blockchain solutions offerings.
- Governments should pay special attention to areas with abundant natural resources like timber, fish, and water.
- Establish an innovation lab (specialized in blockchain competencies and capabilities) in different areas across the country to nurture the skills required for blockchain and other technologies to offer blockchain solutions to the problems of citizens. The initiatives mentioned above of Government will foster the culture of innovation and transform the community towards digitalization and a sustainable environment.

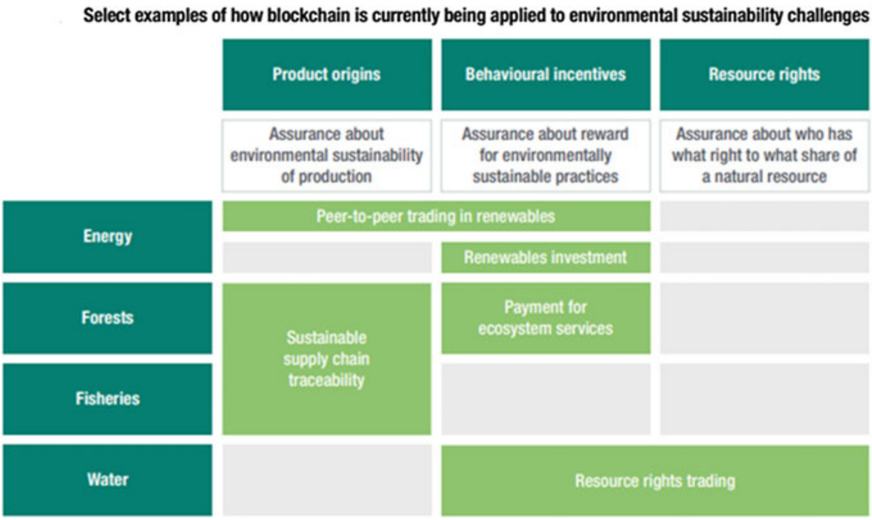

Fig. 2 Blockchain usage to attain environmental sustainability (Miriam et al. 2018)

- Industrialized countries should provide special incentives to blockchain innovators to decrease the environmental mark of the technology.
- Developed countries should provide proper aid/financial and technological support to developing or underdeveloped nations to exploit blockchain technology to foster economic growth.
- Develop the relevant solution of environmental sustainability with the subject specialist of blockchain technology to sense and scan the problem correctly.
- Evaluate and share the benefits of the proposed blockchain solution for the potential environmental sustainability.
- Support the innovators in low-income countries by building strong partnerships to implement the right blockchain technology at the right time and pace.

5.3 Companies Practices for the Usage of Blockchain Technology

Across the globe, it is quite an interesting and appreciable fact that companies are keen to adopt and embed blockchain technology in their infrastructure for better business performance. The adoption of blockchain technology created stiff competition among the companies and was marked as a tool/strategy to achieve sustainable competitive advantage (Pilkington 2016; Yaga et al. 2019). Among all others, few business giants adopted blockchain and achieved numerous benefits out of it. Their names are given as below;

- Amazon
- Dell
- British Petroleum
- Proctor and gamble
- Unilever Corporation.

The explanation of process/mechanism of adoption of blockchain technology and its related outcomes are presented as.

5.3.1 Amazon

Amazon Incorporation is an American International renowned digital company primarily focused on e-commerce, digital streaming, artificial intelligence, cloud computing, and recently adopted blockchain technology. One of the top big five IT companies in the US envisioned continuous technological innovation. Amazon is considered one of the most persuasive economic and cultural forces globally. Amazon managed blockchain to build applications to engage multiple parties for transactions simultaneously without the security of a central/state authority. Amazon is a fully managed service that allows you to join, set up, or control the public or private network with a few clicks. It can handle the demands of thousands of applications

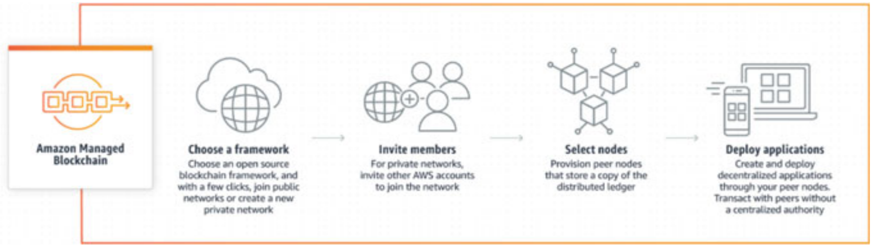

Fig. 3 Amazon managed blockchain (Amazon 2020)

and their related transactions. Figure 3 illustrates how Amazon managed blockchain. Amazon managed blockchain offers various benefits to users across the world;

- **Fully Managed**: Amazon Managed Blockchain facilitates creating blockchain networks with multiple AWS accounts that enable participants/members to perform transactions simultaneously and share data without any centralized control mechanism, enabling a group of members to execute trades and share data without a central authority. Amazon Managed Blockchain removes the need for manual hardware, its software configuration, and its related security components. By using the said blockchain, network participants can add or remove members in the network by using voting power. Managed blockchain allows the member to launch and configure multiple peer nodes on request to perform transactions, and a copy of the transaction record/ledger is stored automatically. Another important feature of Amazon-managed blockchain is that it monitors the network continuously, and the system automatically replaces the weak/poor performer node.
- **Hyper ledger Fabric versus Ethereum (Preview)**: Amazon Managed Blockchain supports two popular blockchain frameworks; (a) Hyperledger Fabric and (b) Ethereum (Preview). Hyperledger Fabric framework is suitable for the applicants who require rigorous privacy and permission control standards with the familiar group of members; for example, a certain business/trading data is only shared with financial institutions. While, Ethereum is considered suitable and relevant for highly scattered blockchain networks in which transparency of data is very important in a network, for example, a network allows the member to verify the user's activity independently, but benefits will be shared across all members.
- **Scalable and Secure**: Amazon Managed Blockchain facilitates the member or applicant to scale their blockchain network as the application usage is continuously growing with time. It allows the network member to remove new nodes by using Managed Blockchain's APIs. Furthermore, Amazon-managed Blockchain used AWS Key Management Service (KMS) to secure the network's certificates.
- **Reliability**: Amazon Managed Blockchain is characterized by improving reliability for 'ordering services.' Hyperledger Fabric framework (HFF) is a digital framework to confirm the transaction's processing and delivery across the

blockchain network. HFF has limitations in storing the record of the transaction's history to keep track. While the ordering service of Amazon is managed, blockchains are built using Amazon QLDB technology, which can maintain the complete log of all transactions, ensure data durability, and ease track the transactions.

5.3.2 Dell

Dell is an American multinational computer and IT technology company that is purely involved in the computer's development, trading, repair, and many other support services for computer-related products and services. It is one of the best PC product companies operating across the world. Dell is a renowned brand for its continuous and dynamic e-commerce and supply chain management innovations. It specializes in the 'build-to-order' and 'configure to order approach.' Initially, Dell didn't focus on the consumer market as it increased the product cost, and profit margin was not acceptable by selling to individual or household customers. But the perception changed when the company's internet site blasted out and got maximum market acceptance. Another major landmark happened when the market accepted Dell with minimum repair needed to be a durable and reliable product.

In the last decade, ORS Group (a global provider of algorithms and software solutions) announced the growing blockchain trend with the blowing wind of new technologies for augmenting their value chains. The tidal waves of continuous innovation and new technologies proved paradigm shifts when many IT dealers and vendors came up with the blockchain initiatives and claimed it as a 'sign of success.' In 2016, Dell Technologies (including Dell Client, Dell EMC, VMware, Pivotal, RSA, Secure Works, Virtustream, and Boomi) created a Blockchain Interest Group (BIG). The steering committee for BIG was assigned to inform and convince the customers about the benefits of Dell's blockchain capabilities. Dell took this initiative to adopt emerging technologies, including artificial intelligence, blockchain, data analytics, and cloud compliance, to maintain its competitive position in the server market. To dive into the tidal waves of upcoming emerging technology, Dell took the following initiatives;

- It has developed its blockchain solution intended to empower the media & entertainment industry to improve the trust and transparency level among all value chain players. It reduces the usage of manual processes and many other inefficiencies related to content rights management.
- Performs real-time auditing and reporting to reduce the stipulated time frame and ensure quality distribution in a cycle. This entire ecosystem of the content management system is featured with smart contracts and highly effective digitalization.
- Developed capabilities regarding digital rights, wallets identifications, micro payments, real-time transactions and sound security system of accounts.
- Dell's embedded the permission-based Blockchain (Ethereum virtual machine abstraction layer) into its engine and algorithms.

5.3.3 British Petroleum

British Petroleum (BP) is a British-based multinational oil and gas company involved in exploration, production, refinement, distribution, trading, marketing, and power generation. BP is also enriched with renewable energy interest (biofuels), wind power, smart grid, and solar technology. In the last decade, the continuous variation in oil prices drags the attention of oil and gas companies to work on the improvement of business operations and cost reduction. In this context, British Petroleum (BP) developed and adopted blockchain technology to capitalize on potential efficiency gains to get a sustainable competitive advantage. Blockchain technology will gear up the BP efficiency in the oil and gas supply chain in terms of speed and verification of transactions. Ethereum technology under the umbrella of blockchain technology offers the benefit of smart contracts to streamline routine business transactions. BP envisioned to get the competitive advantage in the oil and gas sector through;

- Achieve efficiency in oil and gas supply chain.
- Reduce massive paperwork by eliminating the role of middleman.
- Create a blockchain-based trading platform for commodities.
- Reduce risk and cost of physical trading.
- Improve reliability and efficiency of trading operations.

Summing up, there is no overnight solution to adopt and embed technology in a company's systems and processes in entire essence. But it requires sound investment to identify and overcome the hurdles in developing commercially viable technology. A company needs to hire and train a resource person who is already familiar, comfortable, and using it. BP should develop sound networks in the industry to develop rules and regulations to govern the market on an intelligent contract system. They will also have to bring it on board to safeguard it from financial crime. Moreover, there is a dire need to identify the tax collection mechanism as compliance with government tax laws.

5.3.4 Procter and Gamble

The Procter & Gamble Company (P&G) is a well renowned multinational consumer goods dealing in a wide variety of consumer goods, health/personal/family/home care goods, and hygiene goods. Wide range of personal health/consumer health, personal care, hygiene products, and many others. The company expanded its business in different countries specialized in manufacturing and trading. It became one of the best international corporations that acquired many other companies to diversify its product line and ultimately increase its high-profit rate. Procter & Gamble acquisitions include Folgers Coffee, Norwich Eaton Pharmaceuticals, Richardson-Vicks, Noxell, Shulton's Old Spice, Max Factor, the Aims Company, Pantene, etc. The continuous innovation in their products characterizes proctor & Gamble envisioned to improve others' lives. P&G reminisced with its ideology to lead to the industry by developing and adopting emerging technologies (including collaborative robots, motion sensors, Blockchain, 3D printing, augmented reality, voice recognition, and new polymer developments) well before the others.

In line with the innovative philosophy, the company hosts the P&G Life Lab to explore and identify how tech-focused policies, practices, perspectives, and ultimate products bring the dynamic shift/transformation in the industry. A company involved in policy discussions and regulations about the future of blockchain technology across the globe. Moreover, P&G Life Lab was selected as part of the Consumer Technology Association's VIP tours to introduce innovative and exciting products. In 2019, P&G presented the 'Influential tradeshow' at the annual Consumer Electronic Services showcase in Las Vegas to showcase the most innovative intelligent products in the markets. The intelligent products of P&G are named smart toothbrushes, fragrance diffusers, baby care items, razors, and facial skin care devices.

The company launched the high-tech baby monitoring system featured with sensors to record the infant's sleep, feeding, and waste generation. The data gives practical, unique insights and user-friendly recommendations for tired parents to handle the child accordingly.

5.3.5 Unilever Corporation

Unilever Corporation is a multinational consumer good company in Foods/Refreshments, Home/beauty/Personal Care products. Unilever deals in a wide range of fast-moving consumer goods, including food items, drinks, dairy products, cleaning agents, health products, and beauty/care products. Unilever is one of the largest soap producers worldwide and expanded its business operations and trading in almost 190 countries. Unilever is featured with the ownership of 432 brands.

Recently, Unilever has launched blockchain technology as a pilot project to manage transactions and ensure supply chain transparency efficiently. This initiative will surely lead to cost reduction, process efficiency, transparency, consumer trust, and market competitiveness.

Unilever integrated blockchain technology to restructure the data collection, saving, and verification related to the demographic and location of its business. Moreover, Unilever anticipated achieving a desertification-free supply chain by 2023 under blockchain technology by introducing transparent and traceable supply chain processes. Unilever took this initiative to fight the threat of climate change. Unilever claimed to bring media investment at the 'zero leakage' point to scale up the advertisement solutions. Unilever collaborated with IBM Watson Advertising and Media ocean (ad Software Company) to create an ad-buying blockchain solution to save money in reconciling the amount spent on digital advertising.

6 Big Data Analytics

In the early 20000s, companies faced a severe challenge of data scalability. All storage and CPU technologies cannot store, track and analyze the big data in numerous terabytes. According to the TDWA survey conducted in 2009, 38% of companies were already practicing advanced analytics to analyze big data, while the remaining 62% were planning to practice within a few years. So right now, we can assume that all organizations are using advanced analytics to deal with big data. Analytics helps the business predict and explore the environmental, social, financial, and technological dynamics and devise strategies accordingly. Advanced analytics is found the best way to identify market segments, best supplier, best products, market conditions, sales season ability, etc. (Fisher et al. 2012).

To that end, advanced analytics is the best way to discover new customer segments, identify the best suppliers, associate products affinity, understand sales seasonality, and so on. All companies appreciate the way forward towards advanced analytics to achieve market competitiveness. Data analytics is envisioned to explore the new business facts that require a large volume of data to dig out deeply.

Previously, big data was defined and discussed according to its size, but there are also various attributes to elaborate it comprehensively. These attributes are named data volume, data variety, and velocity. The scope of big data affects the process and mechanism of its quantification as analytics techniques vary according to the data set's nature. Another feature to properly understand the meanings of big data is the source of data that where it comes forms. The sources can be web, social media, logs, call center data, or clickstreams. The concept of big data is not new, but the concern is to analyze the more complex data at the erudite level. During the past few decades, it has been observed that different technologies such as statistical or machine learning are used to analyze the more complex and sophisticated data in which manual analysis is not possible to better reflect the hidden patterns, aspects, market trends, customer preferences, etc. for better business decisions. In the broader context, data analytics techniques and related technologies provide the way forward for effective business operations and quality performance. Big data analytics is an 'advanced analytics' to apply complex predictive models and statistical algorithms on large data in raw and unstructured form to make it reliable and useful information. In the current competitive era, it has become a trend for businesses, research institutions, and governments to gather complex data regularly. The current era needs to collect more data about the business, but more data doesn't mean more valuable and reliable information. It may include ambiguous, useless, and abnormal data as it might be possible that a user has multiple accounts or one account is used by various users, affecting the data transparency and accuracy. It may raise privacy, security, and quality issues that need to address first (Cardenas et al. 2013).

It is essential to realize the importance/value of big data to improve business operations, ultimately leading to strong market share and competitiveness. To realize its importance, organizations can use analytical technologies and software to design effective marketing strategies and develop advanced operational efficiency, customized products, and competitive service structure (Zakir et al. 2015).

6.1 The Lifecycle of Big Data Analytics

Here is the complete lifecycle of big data analytics to review;

- Step 1:—Business case evaluation (goal identification)—The lifecycle of big data analytics begins with identifying reason/logic and goals behind the analysis of big data related to the business operation, also named business case evaluation.
- Step 2—Identification of data—In the 2nd phase of big data analytics, it is essential to identify the data type, nature, and sources to access it. It also includes the identification of the process/mechanism to collect it.
- Step 3—Data filtering—This stage includes identifying corrupt/useless data and filtering to remove it before going into the next phase.
- Step 4—Data extraction—In this stage, the data analyst has to trace out the incompatible data with the tool and develop a way to make it compatible for further processing. Data that is not compatible with the tool is extracted and then transformed into a compatible form.
- Step 5—Data aggregation—This stage includes integrating data in a similar context, nature, and type received from the same fields across various datasets.
- Step 6—Data analysis—Proper evaluation of data is required to explore and identify helpful information for effective business decisions using various analytical and statistical tools.
- Step 7—Visualization of data—This stage is characterized by the visualization of data in graphical forms using multiple tools such as Tableau, Power BI, and QlikView, Big Data analysts, etc.
- Step 8—Presentation of Final Results—This is last stage of big data analytics lifecycle in which final results (extracted form analysis) are presented and shared with all the business stakeholders who are influenced by or influence it and take the action accordingly.

The complete big data life cycle is enriched with the complete 8-steps process based on data collection, analysis, interpretation, and long-lasting business impact.

6.2 Different Types of Big Data Analytics (Russom 2011)

There are four different kinds of big data analytics explained below;

6.2.1 Descriptive Analytics

Descriptive data refers to the past data that can also be named as secondary data in a very simple and readable form, even for a layperson. Descriptive analytics helps create a presenting report such as the company's sales, profit, etc.

6.2.2 Diagnostic Analytics

Diagnostic analytics is used to identify or dig down the particular problem, including drill-down, data mining, data recovery, etc. This technique helps the organization get deep insights into the business problems, context, related factors, and intensity of the problem.

6.2.3 Predictive Analytics

This analytics is suitable for the organization to use the historical/previous year's data to forecast or predict the future. It is mostly used to identify the trends related to the market, customers, and related dynamics. Predictive analytics uses techniques of data mining, AI, and machine learning to analyze existing data and forecast the future accordingly.

6.2.4 Prescriptive Analytics

Last but not least, this analytics is based on the solution provider rather than problem identification. The analyst examines the overall market condition, dig out sources of the problem, its ultimate effects, and recommend/prescribe a solution to a particular situation. This type of analytics works with both analytics' types; descriptive and predictive. Mainly, it relies on artificial intelligence and machine learning to offer solutions that fit in with the context.

6.3 Big Data Analytics Tool

Here are some of the tools used by different companies for big data analytics;

- Hadoop—used for data recording and analysis
- MongoDB—suitable for the dataset characterized with the continuous variations
- Talend—best fit for the data integration and its management for effective business decisions
- Cassandra—it is used explicitly for the distributed database to handle the data in chunks
- Spark—suitable for the real-time processing to handle a large amount of dataset
- Storm—used as an open-source digital calculation system
- Kafka—used as a distributed flowing platform to store error and make it compatible accordingly.

6.4 Uses of Big Data Analytics and Examples

There are few examples are given below to explain the mechanism that how big data analytics helps the organizations;

- **Customer acquisition and retention**. Big data analytics is used by Amazon, Netflix, and many more others as a personalization engine to bring the marketing efforts of the company on track to improve the customer experiences and make them loyal. This also offers customized/personalized products for the consumers and retains them for the long run.
- **Targeted ads**. Big data analytics helps the organization extract the data from multiple sources regarding past purchases, consumer interaction mechanisms, viewership history to design a compelling and influential marketing campaign to attract customers on a large scale.
- **Product development**. One of the main features of big data analytics is that it provides deeper insights into the product viability, improvement need, development process to get the best fits for the customer's requirement.
- **Price optimization**. It can help retailers develop or opt for affordable pricing models for the customers and lead to sound revenue generation.
- **Supply chain and channel analytics**. For this, Predictive analytical models are found suitable to dive into supplier networks, stock management, and notification/alerts for potential delays in deliveries to the ultimate customers within the stipulated time frame.
- **Risk management**. Big data analytics closely observe and identify upcoming business operations risks and devise a proper mechanism to handle the risk effectively.
- **Improved decision-making**. By using big data analytics, it becomes easier for the businessman/company to get deeper insights into the business, its growth,

challenges, and potential upcoming opportunities that ultimately lead towards effective decision making.

- **Improve customer experiences**: Another feature of big data analytics is that it can facilitate the organization to keep track records of its customers, their habits, interest, and experiences as Delta Air Lines uses Big Data analytics to monitor tweets of the customer to get to know about their customers' experience regarding their journeys, delays, and so on. The airline identifies the negative tweets and responses and offers possible solutions. This sort of initiative to address the concerns publically can lead towards good customer relations and loyalty.

7 Big Data Analytics and Industrial Ecology

Big data got acceptance universally and is used in multiple areas, fields, industry across the globe. The main focus is identifying the mechanism/process to use it as previously communication and computational infrastructure is used to facilitate its virtual collaboration (Xu et al. 2015). Kraines et al. (2001) developed a geographically scattered cloud-based computational infrastructure into real-time practice.

In addition to virtual collaboration, big data analytics helps measure environmental potential threats and opportunities and human consumption patterns to address them. Industrial average data is used to measure the ecological impacts of products and services. The increasing availability of big data emphasized to the industrial ecologist that there is no need to trace out the data sources and their storage. Still, it should be more focused on utilizing big data and its related analytical tools to complement it with the existing data and methods through multiple interdisciplinary collaborations (Kambatla et al. 2014).

Moreover, big data has the most prominent and direct application in industrial ecology. It facilitates the development of complex system models to understand human behavior better and capture the related features of its dynamics, due to the sufficient big data availability about human behavior (gathered from social media sites) to draw more realistic human behavior dynamics instead of assumptions and hypotheses (Xu et al. 2015).

8 Conclusion

The study is purely intended to explore and discuss the contribution of the technological revolution to revolutionize industries across the globe. The term 'revolution' includes the appliances of (a) new cheap input, (b) new products, or (c) new processes. The strong connection of technological and industrial revolution affects human life's social, cultural, psychological, and economic factors. Whereas, the ecologists are often concerned about the continuous up-gradation and flow of industrial processes, which become environmental threats by maltreating the natural resources and poor mechanism of waste disposal. In this context, there is a dire need to explore the effects of the industrial revolution on environments and devise a proper mechanism to handle the increasing threats/risk smashed by industry.

Furthermore, it is found that companies are envisioned and more interesting in the development and adoption of upcoming emerging technologies (artificial intelligence, cloud computing, blockchain, and big data analytics to cut down costs, increase profitability, and process efficiency that can ultimately lead towards sustainable competitiveness. Therefore, companies expect a bright future and high market potential to lead the generations.

9 Future Research Directions

This study provides a glimpse of the company's vision and practices regarding technological innovations and the ultimate industrial revolution. In this regard, managers and policymakers are recommended to take the following actions to derive the benefits from the strong association of technological and industrial revolution;

- Invest in technological and human resources simultaneously to develop competencies and capabilities sustainable outcomes.
- Requires strong research team to explore the role of emerging technologies and their upcoming effect on the organization and how can organization adopt it, at which time and pace.
- Design a proper mechanism of the utilization of natural resources to remove the environmental threats.
- Create proper awareness in the organizational stakeholders about the development and adoption of emerging technologies and their potential effects on their lives.
- Focus on intra-organizational and intra-industrial collaborations to take the benefits of emerging technologies at the cost of minimum resources for maximum sustainable return.

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The Transition to Renewable Energy—A Sustainability Issue?

Adrian Neacsa, Syed Abdul Rehman Khan, Mirela Panait, and Simona Andreea Apostu

Abstract The new energy transition from conventional (fossil) fuels to methods that use renewable energy is a complex, multifaceted process that is determined both by the pressure on oil and gas reserves but also by the need to use resources with little or no impact on the environment. Population growth, urbanization, intensification of economic activity and globalization are some factors that have generated the increase of energy consumption, the effects on the environment being devastating. The current energy transition is therefore a politically determined process, because the countries of the world have realized the need to take concrete measures to protect the environment. However, the energy transition comes with a series of economic, technical, social and energy security challenges. This chapter aims to identify the main features of the energy transition process in correlation with the analysis of relevant statistical data. In addition, main opportunities and challenges generated by the energy transition for different categories of stakeholders are presented. The results of the analyzes undertaken prove the complexity of the phenomenon, its multidimensional nature and the importance of involving of public authorities and international institutions in the process of energy transition.

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1 Introduction

Mankind has relied, since ancient times, on the use of basic energy sources such as human or animal muscles and the burning of biomass like wood or coal. With the beginning of the Industrial Revolution, a completely new energy resource was identified from the burning of fossil fuels. Energy based on fossil fuels was a key driver of the technological, economic, social progress and development process that followed. Fossil or conventional fuels (wood, coal, gas, oil) are important energy resources and they will play a special role in the world's energy systems, the reasons being economic, technical and political. Population growth, economic development, urbanization generate increasing energy consumption (Fig. 1), which puts pressure on fossil fuel resources and on the environment, given the major challenges posed by climate change and global warming global (Vasile and Balan 2008; Platon et al. 2010; Tlili 2015; Yatim et al. 2016, Day et al. 2018; Panait et al. 2019; Erdogan et al. 2020; Armeanu et al. 2021; Janjua 2021).

Over time, as technical progress and the discovery of new resources, many energy transitions have taken place, from wood (biomass) to other classic methods using natural gas, oil and coal. The World population is currently in a new process of energy transition, with renewable energy being a new source that is increasingly being used given its low or no impact on the environment (Unger 2013; Dusmanescu et al. 2014;

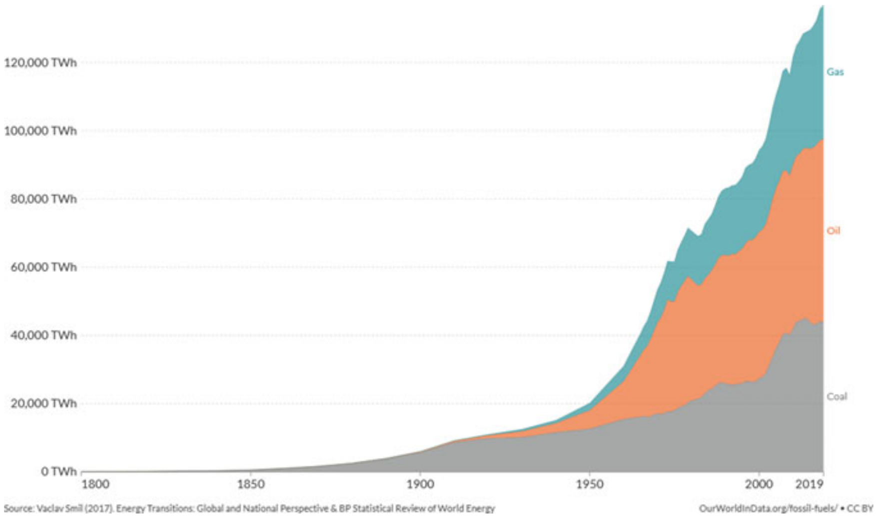


Fig. 1 World classic fuel consumption (natural gas, oil and coal). Worldwide level of the consumption of the energy from conventional sources at, measured in terawatt-hours (TWh). *Source* https://ourworldindata.org/fossil-fuels

Armeanu et al. 2017; Abbasi et al. 2021; Iqbal et al. 2021). The need to reduce the impact of energy consumption and production on the environment has generated the new energy transition, with the concerns of the world's states becoming more and more intense for a greater share of renewables in energy production processes and consumption activities.

Bold goals and concrete solutions have been set both internationally such as the Paris Agreement signed by the world's states in 2015 and regionally, the European Union being a world-renowned leader through initiatives in this field. Therefore, energy transitions have accompanied the economic development of the world's states, being generated by environmental, technical, economic, social and geopolitical motivations (Peidong et al. 2009; Scholten et al. 2020). The actual energy transition is therefore a politically determined process, because the countries of the world have realized the need to take concrete measures to protect the environment. However, the energy transition comes with many economic, technical, social and energy security challenges (Bjegović et al. 2018). Taken into attention the phenomenon complexity of the energy transition, it is necessary to involve all categories of stakeholders. Specialists are needed for the identification and development for the new technologies specific to the renewable energy industry, education being an important component that must be properly valued in order to obtain the expected results. However, researchers draw attention to the negative impact that technical progress has on resource consumption and thus on the environment. Technological innovation generates a decrease in costs and implicitly in prices for natural resources, including energy, which generates an increase in consumption and the manifestation of the Jevons effect (Zaman et al. 2020; Siami and Winter 2021). However, the big challenge remains to achieve a balance between the social impact and the environmental changes caused by the energy transition, because changing the energy mix generates rising energy prices, supply difficulties and short-term crises, the effects being felt not only by companies but also by final consumers. For this reason, energy poverty can deepen in some regions, its effects being devastating economically, socially and even environmentally (Kim and Urpelainen 2013; Aceleanu et al. 2018; Druică et al. 2019; Neacsa et al. 2020). At the level of the European Union, taking into account the impact that the energy transition may have on the population, a set of measures has been adopted to achieve just transition (Eyl-Mazzega and Mathieu 2020; Heffron 2021).

The technical solutions must be accompanied by specific financial instruments, taking into account the need to streamline the energy transition process. Financial institutions need to fuel the innovation process and launch proper instruments given the risks posed by renewable energy investment projects. The high value of investments discourages economic agents from initiating such projects, but the support of public authorities in the form of subsidies or reductions/exemptions from customs duties on imports of green technology can help guide companies towards green energy production. Renewable energy producers' associations are essential in the transition process, given the lobbying activity they can initiate and support in addition to public authorities, thus being an important stakeholder in the energy transition process. (Yatim et al. 2016; Day et al. 2018; Brulle and Werthman 2021).

This chapter aims to summarize the short, medium and long-term perspectives on the future of the use of classic fuels (natural gas, oil and coal—see Fig. 1) and to present the role of these resources in the energy and electricity systems and the possibility of replacing them, as quickly as possible, with modern technologies that use renewable energy from sustainable sources to cover energy needs.

2 The Energy Transition—Challenges and Opportunities

One vital response to Sustainable Development Goals (SDGs) and Paris Agreement, and the recent climate change crisis report is represented by transitioning to renewable energy, increasing energy efficiency and conservation. In order to analyze the most relevant concepts in the field, bibliometric analysis was used, the source of scientific articles, focused on renewable energy transition, being the academic platform Web of Science. Therefore, the content of 492 highly cited articles related to renewable energy transition available on Web of Science have explored, the aim being the highlight the structure of the scientific field. The authors used the content analysis in order to inspect the most common words and the relationship between words. The most common words in the full content of selected articles, apart of the keywords used, are presented in Fig. 2, including “transition”, “energy” and “sustainability”.

Therefore, the pathway to sustainability is based on renewable energy transition. Sustainability in energy domain is related to “technology”, “impact”, “development”, “global warming”, “solar energy”, “change”, “future” (Fig. 3). Climate and nature need to be fully protected, but this can only be achieved throught a sustainable life. The future is reflected by sustainability in terms of renewable energy transition.

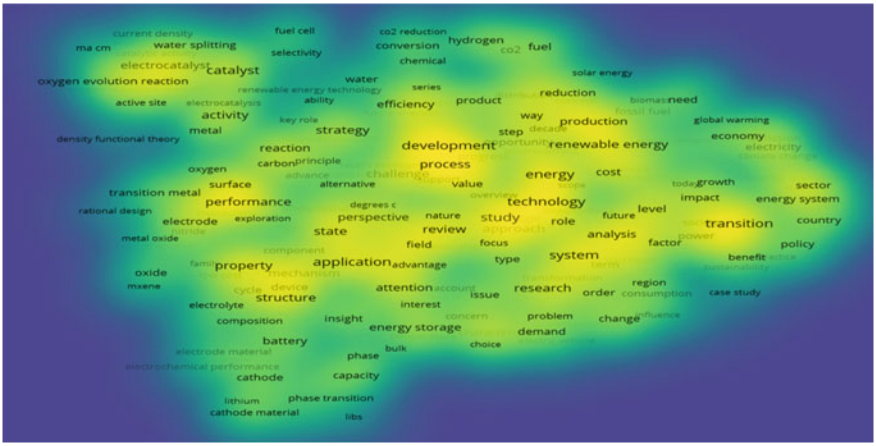


Fig. 2 Common words in scientific publications. *Source* Authors based on articles analysed

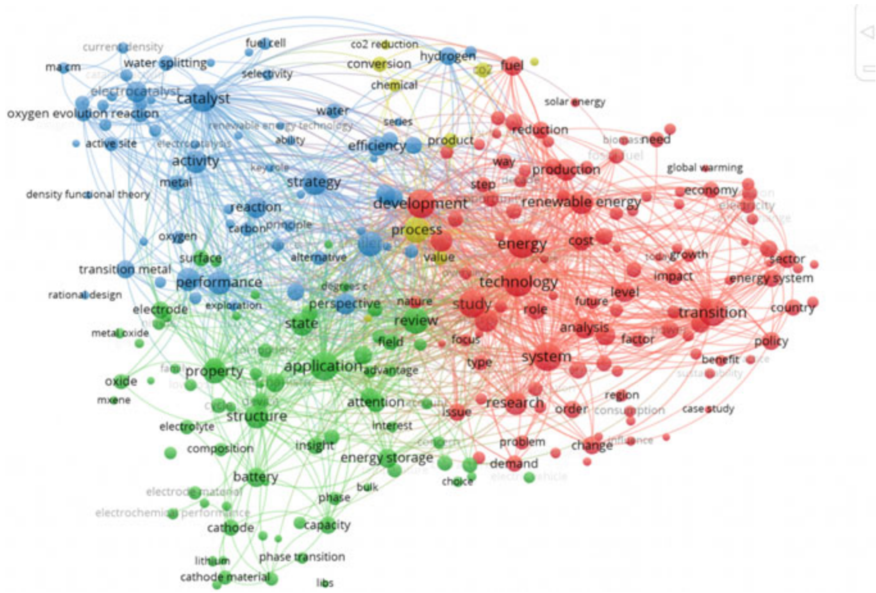


Fig. 3 Word network in renewable energy transition scientific publications' content. *Source* Authors based on articles analysed

The analyzed studies demonstrate different attitudes and behaviors towards the renewable energy process, depending on the type of stakeholder and its possibilities of involvement in such a complex process. The attitude of the countries towards the energy transition is different depending on the level of development. Developing countries use mostly fossil fuels, which have the advantages of availability and low price (Zaidi et al. 2018; Kahia et al. 2019). Therefore, the need to eradicate poverty is more important goal than reducing the negative impact of human activity on the environment. So, "rising carbon emissions due to non renewable energy consumption continues to challenge sustainable development in the developing economies"(Hanif 2018, p. 15066). The countries' priorities are different depending on the level of development but also on the endowment with resources (Stambouli et al. 2012; Andrei et al. 2017; Schiffer and Trüby 2018; Khan et al. 2020; Sohag et al. 2020; Murshed et al. 2021; Shahzad et al. 2021a). The access to affordable and clean energy is one of the sustainable development goals set by the United Nations, which indicates the importance of energy in developing countries. These countries are experiencing sustained population growth, which is why in the face of limited fossil fuel resources, the promotion of renewable energy and increased energy efficiency are essential to ensure access to energy for all until 2030. Developed countries are much more involved in the energy transition process because they have the financial strength and the political determination to make the smooth shift from classical fuels to green or renewable energy. The European Union is a pole of excellence in this field as well, daring objectives being achieved by the establishment of the European Energy Union, by approving the Green Deal (Fattouh et al. 2019).

The energy transition poses significant challenges for oil-exporting countries and for companies operating in the oil and gas industry. Oil companies need to reconfigure their business model to adapt to the structural changes that accompany the global transition process. The paradigm shift in the energy field forces oil and gas companies to integrate low-carbon resources into their business, and the major challenge is to synchronize the investment process with the changes taking place nationally and internationally so as to keep up with competing companies. Gradually, these companies turn into oil companies into full energy companies, the pressures being multiple and exerted by stakeholders such as shareholders, competition, climate activists, public authorities or financial institutions (Fattouh et al. 2019; Pickl 2019). Some of these companies have even rebranded, but some stockholders claim the use of companies as a greenwashing technique that is not based on real involvement in the pass to the low carbon economy (Vollero et al. 2016; Palazzo and Siano 2019). For example, the $200 million campaign launched in 2001 by the British multinational petroleum company—BP had the aim of rebranding of BP in Beyond Petroleum.

The energy transition also poses major challenges for countries with significant oil and gas reserves that see the threats that may arise from declining export earnings and the inability to capitalize on their natural resources. The consequences are multiple and affect not only local companies, public authorities but also the population that will face disruption of their socioeconomic wellbeing. Given that the energy transition process is sustained internationally, these countries must also be part of this trend of increased environmental awareness and have embarked on bold projects to integrate renewable resources into the national energy mix, given the natural potential, which they have especially for the production of solar and wind energy (Stambouli et al. 2012; Fattouh et al. 2019; Pickl 2019; EEA 2021; IEA 2021).

More and more voices are drawing attention that the processes of producing energy from burning fossil fuels come with major negative externalities (Yatim et al. 2016, Shahbaz and Balsalobre 2019). The combustion processes of these fossil fuels, for the production of various forms of energy, generate a very high content of the CO_2 (carbon dioxide) and other polluting gases which are the biggest influencing factor in terms of global climate change. In addition, the air pollution, a harmful phenomenon, generates every year, millions of premature deaths and causes disease of the population, which puts pressure on the public health system, the economic consequences being borne by the public budget (Hao et al. 2018; Mujtaba and Shahzad 2021). As the development of technologies and the diversification of availability of sustainable low-carbon energy sources (nuclear and renewable), the world must rapidly abandon the technologies based on the use of fossil fuels (Fig. 4).

Renewable energy is viewed with interest not only by public authorities but also by companies because the energy transition also generates business opportunities for firms in various fields (Shem et al. 2019). In addition, taking in account the characteristics of renewables, local communities are interested in renewable energy projects (Strachan et al. 2015; Aceleanu et al. 2018). The investment policy of the companies is

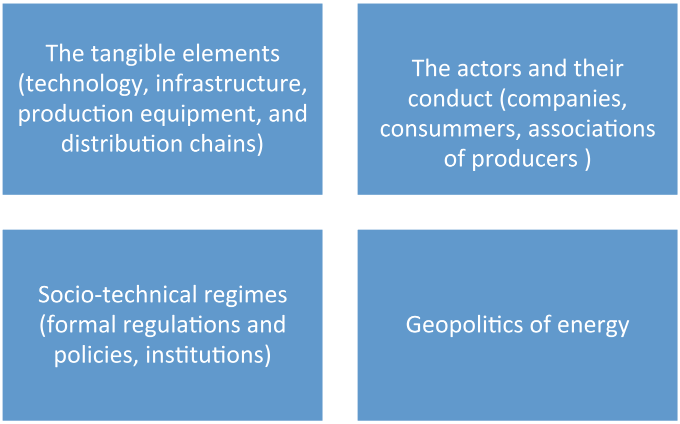


Fig. 4 Dimensions of energy transition. *Source* Developed by authors based on Fattouh et al. (2019)

in a continuous metamorphosis. More and more companies are reducing their investment in fossil fuels and turning their funds to green energy projects. Therefore, divestment and reclamation are the new watchwords that synthesize the activity of companies in various fields. Portfolio investors are also increasingly involved in supporting the energy passing process by sanctioning oil and natural gas companies and by directing funds to those companies that promote the use of green energy. Therefore, socially responsible investors require companies to adapt to the new energy transition. Financial institutions are also interested in the energy transition process to provide funding to companies that finance various renewable energy projects. For this reason, energy finance is a new segment of the financial market that provides specific tools, mechanisms and products for financing the energy transition. So, the energy transition is "multidimensional, complex, non-deterministic, non-linear and highly uncertain process" (Fattouh et al. 2019; p. 46) In addition, it is considered a multilayered process with various players (Fattouh et al. 2019).

3 The Evolution of Methods for Obtaining Energy from Renewable Sources

The use of renewable energy sources (Fig. 5) has benefited from a remarkable evolution in the last decade. For the next period, the forecasts are encouraging because this issue is in the attention of all kinds of stakeholders like organizations for environmental protection, public authorities, energy companies, portfolio investors, financial institutions. Given the premises of innovation, increased competition, legislative framework and political support in many countries, renewable energy technologies have made great advances and sharp reductions in costs, in recent years. Taking into account the above, it can be emphasized that their development has come to surpass

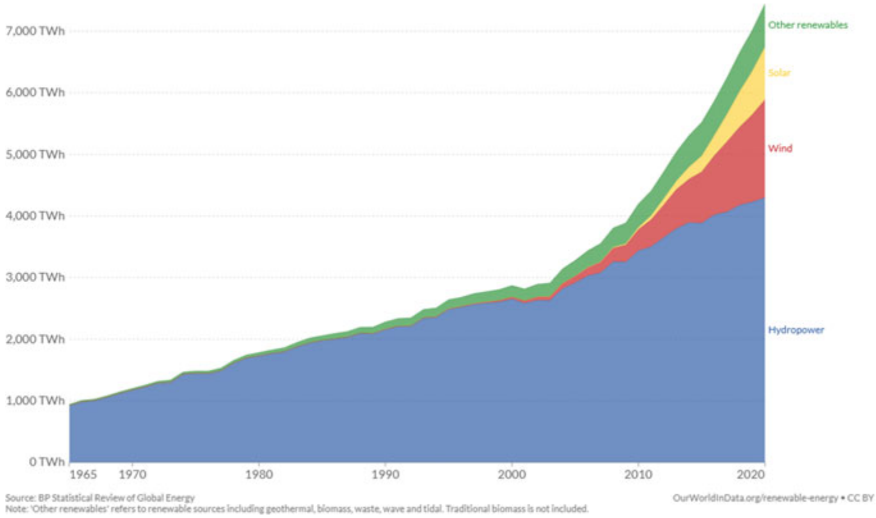


Fig. 5 Global renewable energy production. Worldwide level of renewable energy production by sources, measured in terawatt-hours (TWh). *Source* https://ourworldindata.org/renewable-energy

that of any other energy source. This process is politically driven, and public authorities have the essential role in this transition by elaborating strategies, establishing concrete measures and objectives. Some countries have set very bold targets, such as Sweden, which aims to phase out fossil fuels by 2050, setting "CO_2 levy and a comprehensive environmental tax reform" (Adebayo et al. 2021, p. 1884).

The COVID-19 crisis has created new challenges for the energy transition process because, on the first point of view, the decline in economic activity has had a lower impact on the changes in environment, but on the other point of view, some of the financial funds that should have been used to finance projects of green energy has been redirected to affected sectors such as the medical system. So, certain publicly funded renewable energy investment projects have been postponed due to the redirection of funds to combat the effects of the crisis. The activity of energy companies has been affected, the World Bank considers that this crisis has interrupted the electrification efforts (WB 2020), which calls into question the achievement of SDG 7 (which includes universal access to all sources of the energy by 2030). However, renewable energy has set a record by creating new energy capacity in 2020 (investment projects initiated in previous years were completed in 2020) and has been the main source of electricity production which has seen a net increase in total capacity. For a period of three years in a row, although the level of investment in new sustainable energy capacity has risen slightly, corporations have continued to break records for renewable energy supply.

More and more countries have channeled their attention to renewable sources sources for electricity and heat. Although the production of biofuels for transport activities has decreased, sales of electric vehicles (EVs) have expanded, as has the link between electric vehicles and renewable energy, albeit to a lesser extent. In view of the above, China has set a neutral target for greenhouse gas emissions, especially carbon, and is among the first countries to strengthen its commitments to take action against the climate crisis. Following the installation of Joe Biden in the White House, the United States rejoined the Paris Agreement in early 2021.

At the same time, all obstacles from previous periods to progress in the renewable energy sector continued to persist throughout 2021. These obstacles have been the slow growth of the share of renewable energy sources in total final energy consumption, inadequate innovation and endowment in some industrial sectors, the need to develop specific infrastructure, lack of accessibility in emerging markets, lack of sufficient policy and law enforcement as well as continuing to provide support for fossil fuel consumption. Also, in 2021, investments in new technological capacities for the production of renewable energies exceeded the value invested in the capacity to produce energy from burning fossil fuels. Thus, most of the new installed renewable energy generation capacity is currently found in both developing and developed countries. For each country that develops renewable energy production capacity, they are considered a mature, secure, cost-effective and sustainable technological option in terms of energy supply to support continuous and at the same time socio-economic development combating climate change and local environment changes caused by air pollution.

The number of countries with policies to support renewable energy did not increase compared to the previous year. Although there is a growing interest in zero targets for greenhouse gases during 2020, there is certainty that they do not cover all greenhouse gas emissions or the sectors that produce them, nor do they necessarily lead to increased attention to the renewable energy sources or to succeed in achieving renewable energy targets. Although such targets are in place in almost all countries of the world, many countries have failed to meet their 2020 targets in many areas, many stakeholders have not yet set additional targets, as their 2020 targets have expired (see Annex 1). Also during this period, investments in fossil fuels highlighted in the global COVID-19 recovery packages were six times higher in comparison to the levels of investments for renewable energy sources. However, not all progress so far has been the same in different countries and sectors. Several types of barriers (policy and regulatory, institutional, economic, market related, technical, information, social and environmental barriers) to the implementation of renewable energy have been identified. For this reason, the rates of penetration of renewable energy in the energy mix of each country are different, the endowment with natural resources being essential (Painuly 2001; Gielen et al. 2019; Kumar and Pal, 2020).

Despite important progress in the energy sector, technologies and methods for generating energy from renewable sources lag behind and cooling and transportation applications, with fewer countries implementing regulations for these end uses. As renewable technologies develop, policy makers face newest challenges. The rapid expansion of methods to obtain energy from variable renewable sources, such as solar energy from the use of photovoltaic systems and energy from windmills, requires very flexible energy systems useful in ensuring the reliability and cost-effectiveness of integrating such systems. In general, in the future, regulatory approaches to renewable

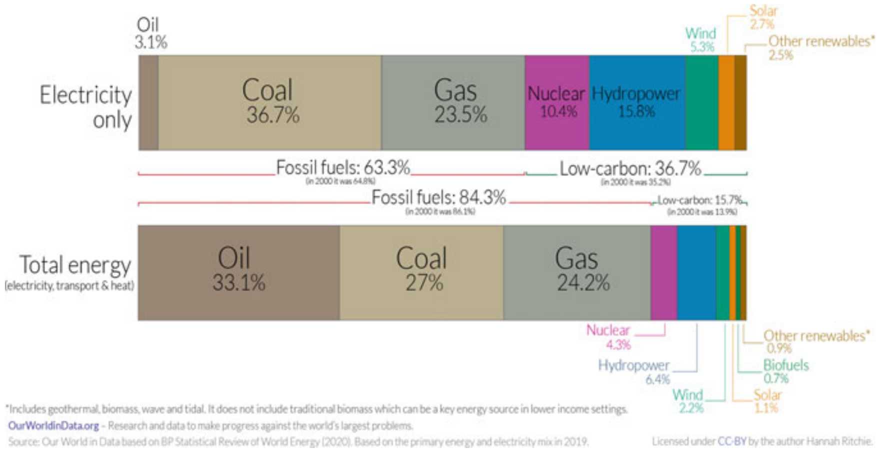


Fig. 6 Global electricity sources. *Source* https://ourworldindata.org/electricity-mix

energy will need to be more compact and complex to reflect the changes and transformations brought about by changes in technology in the energy sector, economy and society (Peidong et al. 2009).

As in the previous period (see Fig. 6), a large part of the passing to green/renewable energy was in the electricity domain (36.7% renewable sources); it can be concluded that the electricity consumption was about 17% of the total final energy consumption. Also in 2019, within the sector specific to transport activities, energy consumption accounted for about 32% of the total final energy consumption and had the lowest share of renewable sources (3.3%). The rest of the thermal energy consumption, which includes space heating and cooling and the heat needed for industrial processes, accounted for more than half (51%) of the total final energy consumption and of their total, renewable sources provided about 11%. Over 35% of global electricity comes from sustainable low carbon sources but these sources cover 15% of total energy.

In 2019, modern technology in the domain of renewable energy (neglecting the biomass usage) accounted for about 11.2% of total final energy consumption, up 8.7% from the reference year 2009. Although there is an increase in the consumption of energy from renewable sources in some sectors, the share of energy obtained from the use of renewable sources has increased only slightly each year. The situation presented is due both to the increase in global energy demand and consumption as well as the continuous investment in new technologies for the use of classical fuels and the reduction of the traditional use of biomass (which led to the transition to fossil fuels).

Slow progress in this area indicates the complementary and fundamental roles of energy conservation, energy efficiency and renewable energy sources in reducing fossil fuel consumption to meet global energy needs and reducing greenhouse gas emissions. As the concentration of CO_2 (carbon dioxide) emissions in the atmosphere continues to rise and exceeds record levels, it has become increasingly clear, that major structural changes are needed to achieve medium and long term, climate change reduction targets. Given the premises created by the rapid evolution of technologies for obtaining energy from sustainable sources and the economic implications of implementing these solutions, it can be said that renewable energy is good for the planet and, ultimately, for society. Some of the plausible reasons that are offered are, among others, the following:

- Influence on the environment: fossil fuels release greenhouse gases into the atmosphere, which affect the planet. Increasing sea and atmospheric temperatures through the greenhouse effect that causes melting ice caps and rising sea levels. The term "global warming" was coined for these purposes (Royal Society 2020; EPA 2020).
- Influence on health: polluted air causes respiratory and cardiovascular diseases and acid rain (Chau and Wang 2020).
- Creating sustainable energy: fossil fuels in general and crude oil and coal in particular are finite resources, and nuclear energy is associated with hazards and problems such as waste handling, causing a negative attitude from the general public. Renewable energies such as solar energy, geothermal energy, energy from the exploitation of river basins and wind energy are attractive and safe alternatives for the environment (Armaroli and Balzani 2011; Dusmanescu et al. 2014).
- Influences on the economy: installations used to produce renewable energy are initially expensive but cheaper in the long run, because it is not necessary to use convetional fuels (Kilinc-Ata and Tanriover 2018).

So, one of the most challenging problem that affect the humanity is the climate change. These climate changes affect hundreds of millions, even billions, of human lives, countless species and ecosystems, the health of communities and thus the viability of zonal economies, in conclusion, the future of planet Earth! Fortunately, the problem of climate change could be solvable. Innovative technologies and scientific discoveries are available, but, in the same time, leadership and courage to change course are needed. In order to solve the problems that cause climate change, it is necessary to go through some stages, presented in the following, and which have a logical sequence.

- ***Reducing the pollutant emissions***. The emissions of the gases such as carbon dioxide and other gases from the combustion of hydrocarbons, fossil fuels and natural gas that capture heat are the main factors accelerating global warming (see Fig. 7). While climate change cannot be stopped, harmful gas emissions can be reduced by applying technical and legislative measures in this area (Shahzad et al. 2021b; Yu et al. 2022).

In order to reduce or eliminate the worst consequences of climate change, it is necessary to reach the target, set for the year 2050, or earlier, of the carbon "Zero Net". "Zero Net" means that, in general, no more carbon surplus is released into the atmosphere than that resulting from energy production processes. Although it is desired to achieve "Zero Net" goal, the estimates are not very encouraging (see Fig. 8). In order to achieve the goal of "Zero Net" emissions, a radical transformation

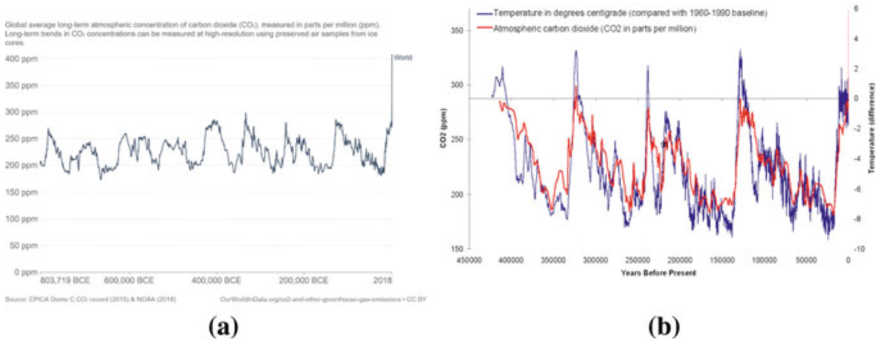


Fig. 7 The emissions of the CO_2 and the temperature evolution **a** evolution for the atmospheric concentrations of; **b** Brighton Chart (The evolution of CO_2 and temperature in the last 400,000 years). *Source* https://bobgnote.wordpress.com/2014/04/05/heres-400000-years-of-atmospheric-co2-and-global-temperature-extrapolation-plotted-by-brighton-uk/

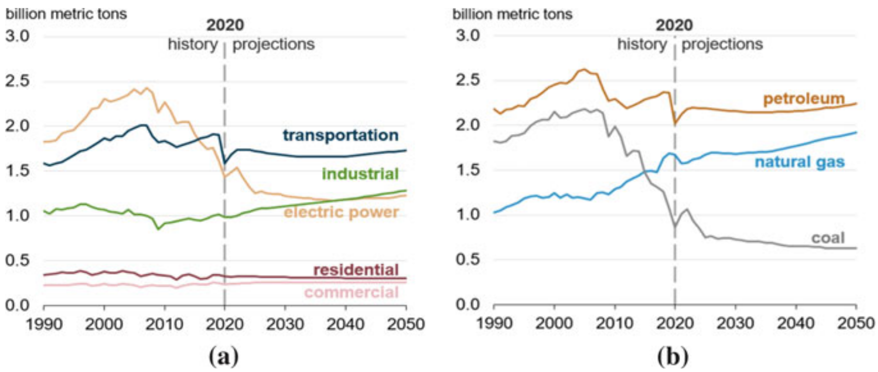


Fig. 8 Energy-related carbon dioxide CO_2 emission **a** by sector; **b** by fuel. *Source* U.S. Energy Information Administration, Annual Energy Outlook 2021, February 2021

of the way in which energy are produced and consumed. It is imperative to improve both the transmission and storage systems and the distribution networks of the forms of energy. Oxygen sources, green spaces and forests must be protected by stopping deforestation. It is also necessary to encourage the development of organic farming. The level of these changes will require a significant global legislative policy focused on reducing carbon emissions. In addition, international cooperation are needed: The Paris Agreement, signed in 2016, reflects the best effort of all states to address the climate change that has occurred so far, although provisions on reductions the emission with greenhouse effect that are not included here. There is much more to be done—and we need to take as much action in this area as possible.

- ***Reducing the level of the carbon dioxide***. In order to achieve the goal of "Net Zero" emissions, it is necessary to take much more action than to reduce emissions,

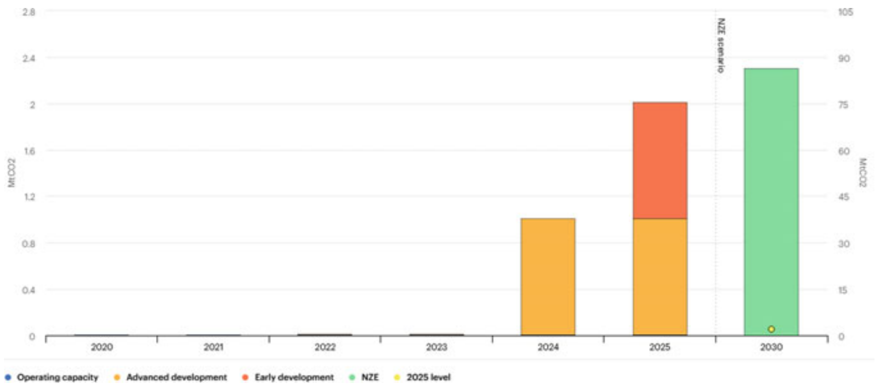


Fig. 9 The "Zero Net" scenario for the period 2020–2030. Direct capture of CO_2 from the air. *Source* https://www.iea.org/data-and-statistics/charts/co2-capture-by-direct-air-capture-in-the-net-zero-scenario-2020-2030

namely to actively eliminate carbon dioxide released into the atmosphere or to offset its effects with some corrective action. A much simpler way to do this is to plant new forests or restore old ones (afforestation). Other corrective ways to improve land management can help (see Fig. 9), as can new technologies that extract/remove CO_2 from the air ("direct carbon capture") or help prevent these greenhouse gases. Leave the chimneys by filtration ("carbon capture and storage"). The level, speed and cost of carrying out such actions are the main barriers to all these technologies and approaches. In all countries of the world, strong state-level policies—and large-scale research and development studies—should be crucial actions (Lund and Mathiesen 2012; Mikulčić et al. 2019; Wilberforce et al. 2021).

- ***Fight disinformation and fake news***. For many years, experts in major media concerns, partisan non-governmental organizations and special interest groups funded by companies that use fossil fuels/hydrocarbons/natural gas in production processes have denied the truth about global warming. All of the above mentioned minimize and distort evidences of climate changes, do the lobby for policies that encourage polluters and try to undermine existing pollution regulations. These waves of misinformation affect the civil society and confuse the population with the growing consequences of global warming. Until the influence of these special interests will be diminished, actions to protect the climate will be much more difficult. The distribution of "fake news", information that mimics credible reports in format, but not in content or intent, is a potential threat to public health and democracy by misinforming citizens. It is imperative to be aware that false news radically influences the population and how it affects relevant beliefs and decisions for policy makers, in order to inform the policies and practices they address. The effect of exposure of the population to false climate news was identified as low on any of our three dependent variables. The magnitude of the effects associated with exposure to false climate news had very little impact, and demographics and political ideology were stronger predictors of beliefs. Research on climate

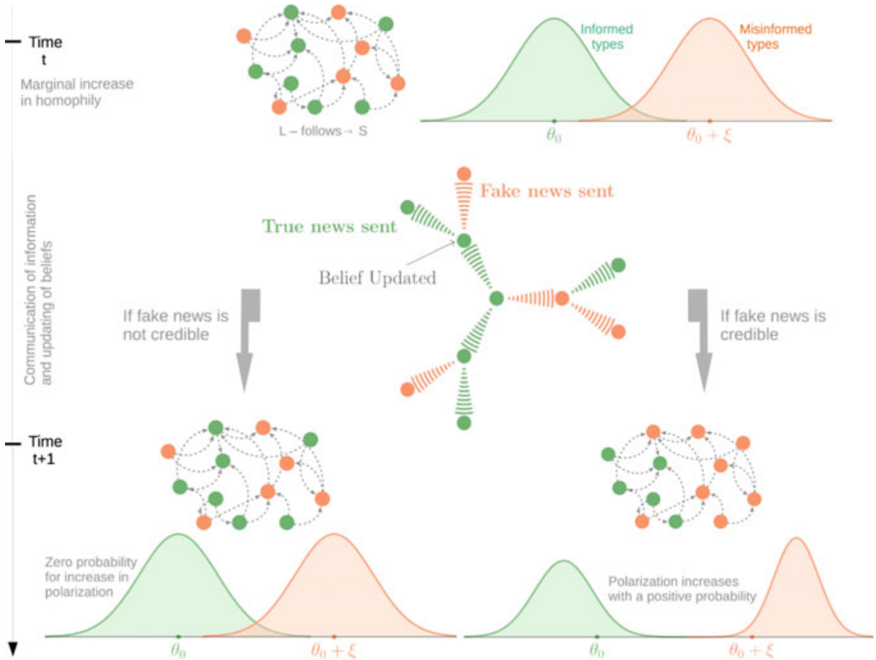


Fig. 10 Belief updating model. *Source* Samantray et al. (2019)

change suggests that exposure to false climate news is very unlikely to have a strong influence on climate skepticism. In Fig. 10, the increase in the polarization pattern at time t + 1 due to the increase in homophilia is presented (based on beliefs, for example, the reality of climate change) at time t. There is a zero level of probability for such a growth scenario dissipation in social networks have a zero level of credibility (Samantray and Pin 2019).

- ***Prepare and adapt***. No matter how quickly measures are taken to reduce greenhouse gas emissions, the reality is that many of the effects of climate change are inevitable and irreversible (temperature levels break records year after year, sea levels rise, and floods, droughts and extreme weather affects many areas). Reducing carbon dioxide and greenhouse gas levels is the only long-term solution to avoid the negative impact of human activity on climate. These complex actions must be channeled towards reducing urban and industrial development in high-risk areas, water scarcity, building green cities and more resilient communities. The level of investment needs to be directed towards scientific research, judiciously justified in terms of social impact and focused on the areas where this impact produces the best results—often in vulnerable communities in terms of energy poverty, as well as in communities with special status (Aceleanu et al. 2018; Druică et al. 2019; Neacsa et al. 2020). Figure 11 shows a scenario in line with the 2018 legislation. For comparison, the global trends for the "No Air Pollution Policies" and "Clean Air" scenarios are presented. Many of the

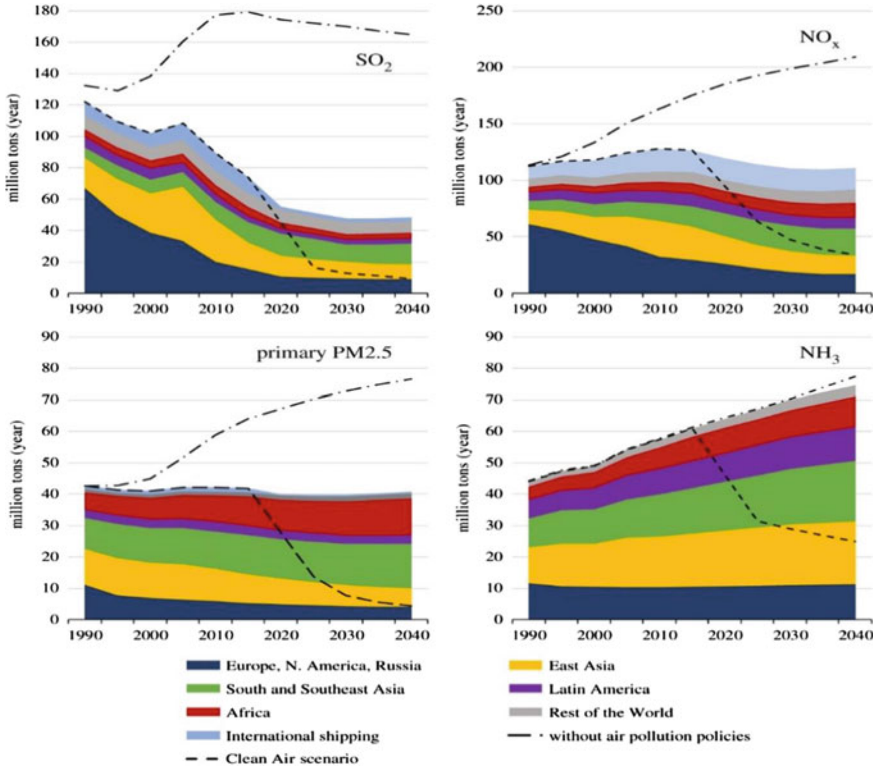


Fig. 11 Global emission trends 1990–2040 assuming effective implementation and enforcement of all pollution controls that were decided by 2018. *Source* Amann et al. (2020)

measures in the Clean Air scenario will not only reduce emissions of very small particles (PM2.5 precursors), but also the levels of other substances that contribute to global warming. As a result of the deep restructuring of the energy system in the "Clean Air" scenario, it is estimated that CO_2 emissions in 2040 will reach a level about 40% lower than those provided in the 2018 legislative standards, CH_4 by about 33% and carbon black about 90% smaller (Fig. 11). Measuring the level of temperature impact of these long-lived and greenhouse gas reductions as well as short-term climate pollutants exceeds the scope of this paper. Also, there is no quantification of the reductions in N_2O emissions that can be recorded in the case of reducing the use of mineral fertilizers and the more efficient use of nutritious manure.

- ***Actions***. No matter how good the ideas of policies and actions in the world, in this field, no positive results will be obtained if there is no cooperation between environmental activists, energy experts and consummers, for a common fight for change. The International Community of Scientists has worked on complex studies and proposed short, medium and long-term solutions to prevent the phenomenon of global warming. Experts and activists in the field of environmental protection and prevention of climate change are campaigning to reduce emissions from the energy and transport sectors; highlighting climate impacts; and the struggle for responsibility by large companies that use fossil fuels/hydrocarbons/natural gas in the production processes of various forms of energy (NBS 2021).

4 European Union and Energy Transition

The European Union authorities has created a general framework, common to all states, through which the policies implemented at the level of each Member State can ensure that reducing carbon emissions is a matter of law and that all members of the European Union must respect it. Some of the targets set by the European Union include reducing greenhouse gas production by monitoring carbon emissions and carbon limits, using the EU Emissions Trading Scheme and the carbon emissions to ensure that project and policy implementations do not have a negative impact on climate change.

The energy transition is a very important issue and the European authorities have set bold goals for the Energy Union created in 2015 in order to increase energy independence for member states, further combat climate change, increasing the level of green energy in the European energy mix, improve the accessibility of energy use by consumers and companies (EU 2021a). In this way, the European Union is taking important steps to comply with its obligations under the Paris Agreement on Climate Change (EU 2021c). The decarbonisation of the European economy is a bold goal set by the European Green Pact, with the transition to clean energy being one of the most important directions for action in EU countries. Through concrete measures, EU countries aim at interconnecting energy systems and integrating renewable energy resources, increasing energy efficiency, green product design, combating energy poverty (EU 2021b).

EU Emissions Trading Scheme is part of EU policy of slowing down and/or combating climate change (see Figs. 12 and 13). The rules for the application of this mechanism and the implementation steps allow for a significant reduction in greenhouse gas emissions. This scheme sets a maximum limit for the amount of greenhouse gases that can be produced. Multinational companies have the opportunity to purchase emission certificates up to the standardized ceiling level, and these certificates can be traded on the market or on the stock exchange, depending on demand and supply like a common commodity (Schleich et al. 2009; Marin et al. 2018).

Energy Union. Given the challenges posed by climate change **(more than 75% of the EU's greenhouse gas emissions are generated by the** production and use of energy) but also the need to increase energy independence, the European authorities have initiated the creation of the Energy Union, which must ensure the fulfillment of three fundamental objectives—access to energy, energy security and reducing the

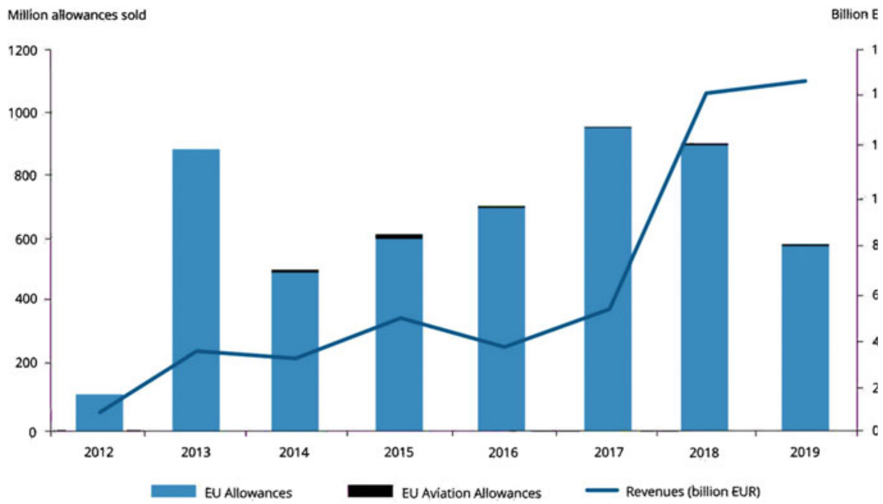
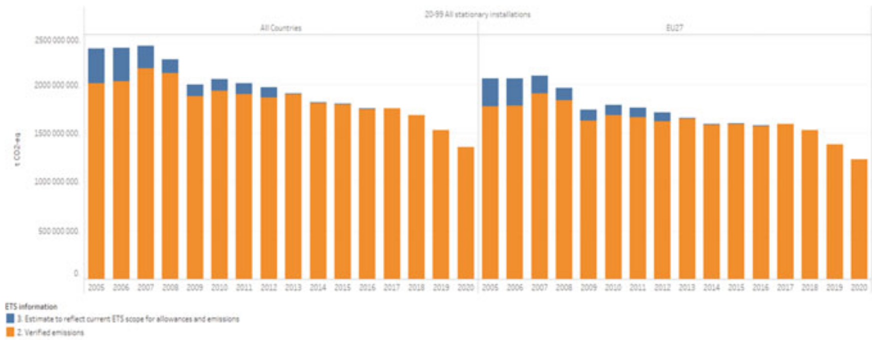


Fig. 12 EU emissions trading system (ETS) auctioning amounts and revenues for the third trading period (2013–2019). *Source* https://www.eea.europa.eu/themes/climate/the-eu-emissions-trading-system/the-eu-emissions-trading-system



(a) (b)

Fig. 13 Historical emissions **a** all countries; **b**. EU 27. *Source* European union emissions trading system (EU ETS) data from EUTL provided by European commission, European environment agency (EEA)

impact of energy production and consumption on the environment by increasing the share of renewable energy in the energy mix (EU 2021a). In order to achieve these goals, concrete targets have been set (1) reduction of greenhouse gas emissions by 40% by 2030 compared to 1990 levels (2) at least 27% of energy consumption must be provided by renewables by 2030 (3) improvement in energy efficiency with 27%; (4) completion of the internal energy market until 2030. The concrete measures

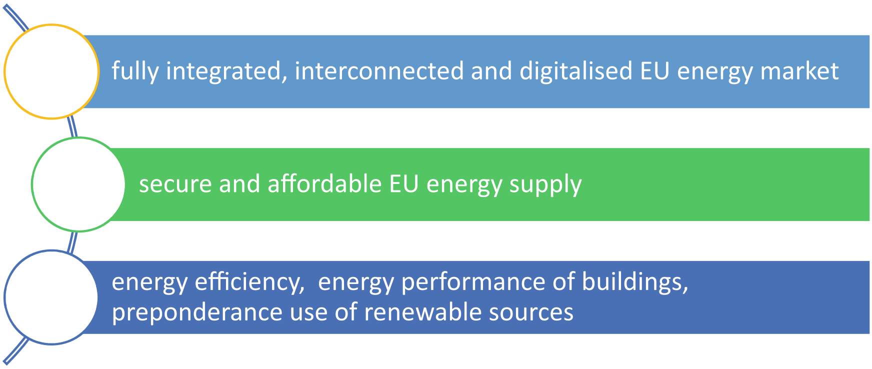


Fig. 14 The three key principles for the clean energy transition. *Source* Authors based on European Union (2021c), energy and the green deal | European commission (europa.eu)

adopted by the European authorities are diverse considering the complexity of the phenomenon and the categories of holders involved.

The European Green Deal is an important document that will ensure the transition to low carbon economy in the member countries (EU 2021b), the energy sector being one of the priorities in order to reduce greenhouse gas emissions and improve the quality of life of european citizens (EU 2021c). Therefore, the environment is a major priority but the social aspects of the transition are not neglected, consumers being the center of attention of public authorities (Fig. 14).

The Covid-19 pandemic has had a significant impact on the energy consumption of all EU Member States. At 2020, after two years of moderate declines, energy consumption from the use of traditional EU sources (for all energy-consuming industries) has seen a historic decline. Thus, it can be seen that the final energy consumption (for end users) also decreased significantly, with a less pronounced trend. This has helped the EU meet its 2020 energy efficiency targets for final energy consumers (Fig. 15).

Returning to previous levels of energy consumption must be avoided. Also the reductions in polluting emissions as soon as possible remain necessary in order to meet the EU's 2030 (Fig. 16) and 2050 energy and climate targets.

According to initial EEA estimates, final energy consumption (FEC) in the European Union states fell sharply by 5% over the one-year period between 2019 and 2020. Measures taken at Community level in response to the effects of the Covid-19 pandemic have led to conclusive results which show the lowest annual rate of decline from 2009 to the present, reaching the height of the financial crisis. In 2020, the FEC fell to around 940 million tonnes of oil equivalent (Mtoe), the lowest level since the early 1990s and only comparable to the last period in 2014. Also, due to the blockages registered at Community level, the transport industry suffered the most, the decrease with an estimated percentage of 12 compared to 2019. This is a phenomenon with significant effects that caused sharp decreases in the trend. After a period of growth

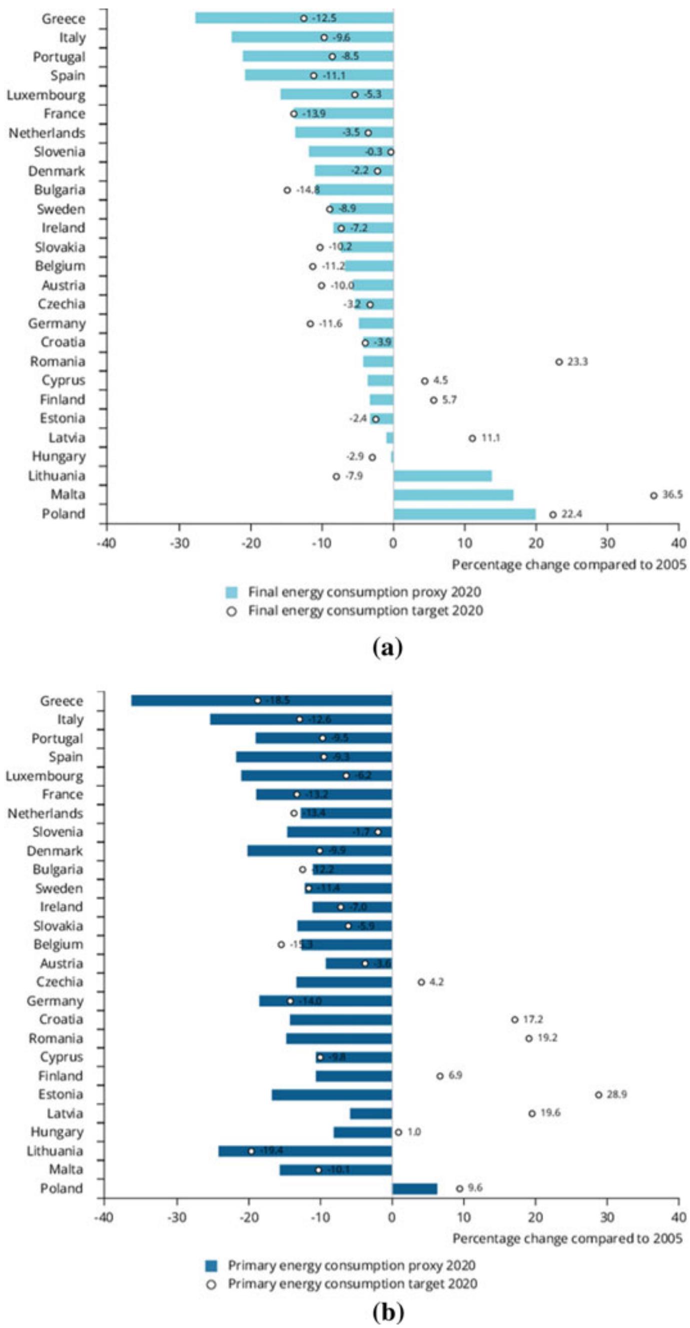


Fig. 15 EU Member States' targets and energy consumption for 2020 final energy **a** consumption FEC; **b** primary energy consumption PEC. *Source* https://www.eea.europa.eu/ims/primary-and-final-energy-consumption-1

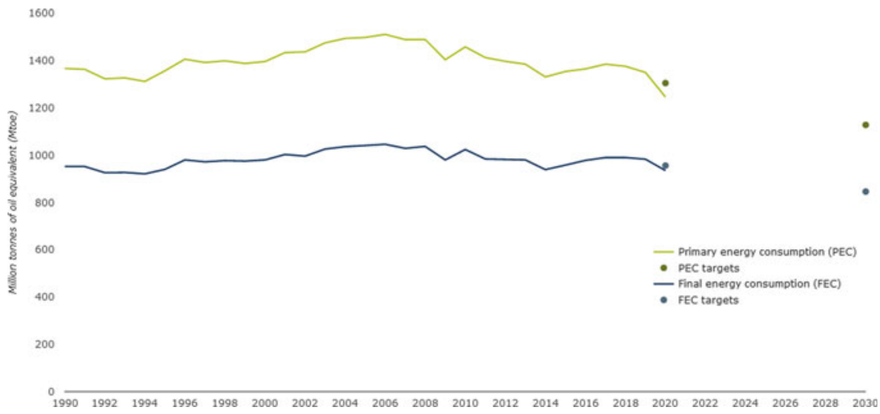


Fig. 16 Primary and final energy consumption (PEC and FEC) in the European Union. *Source* https://www.eea.europa.eu/ims/primary-and-final-energy-consumption-1

of 7 years. With the significant decrease of the activities in the industrial fields registered at the level of 2020, the importance of FEC in the industry decreased by a level of approximately 0.056 compared to the value registered in the previous year. Other sectors of activity (mainly construction) remained relatively stable.

A much more significant decrease was recorded in the case of energy consumption obtained from primary sources (PEC). Also in the same period of 2019 and 2020, the PEC registered a decrease of 7.7% points (a decrease of 4 times compared to the level recorded in the previous year) to a total of 1,246 Mtoe, registered as the lowest percentage level of when data from complete records were available. Following the trend of previous years, the use of conventional/solid fossil fuels decreased the most in percentage (19). Unlike the previous period, the use of conventional/liquid fossil fuels, nuclear fuels and, to a much lesser extent, natural gas also decreased significantly during 2020. The shift from the use of fossil fuels methods of using renewable energy sources have also reduced the level of the PEC, while the share of renewable energy in the EU has doubled from 2005 to the present.

Records from EEA studies mentioned in previous paragraphs indicate a historical decrease in the level of energy consumed due to the influence of the pandemic caused by Covid-19, while increasing the level of decarbonization of emerging energy systems. According to these records, it can be seen that the European Union has been able to meet its energy efficiency targets by 20% compared to the 2007 baseline scenario for 2020. EEA records have shown that in 2020 the percentage levels of the PEC and FECs were 5 and 2.4, respectively, lower than the targets set. However, the reductions in consumption caused by the Covid-19 pandemic may be short-lived if not supported by structural changes. With regard to medium and long-term energy strategies, Member States need to make sustained efforts to further reduce their energy consumption. All this action is needed if the EU target is to reach the target of 32.5% by the end of 2030. In addition, the European Commission has recently proposed changing several targets in the framework document “Energy Efficiency

Directive" for 2030: 36% for the FEC and 39 for the PEC, paving the way for the overall goal of neutralizing carbon sources by 2050.

In line with the above EEA estimates, they have been implemented for almost all EU Member States, with the exception of only five, two (Hungary and Croatia) in which the FEC fell between 2019 and 2020, and three (Portugal, Luxembourg and Malta), with the largest reductions. Of all the Member States of the European Union, only twenty-four countries have reduced their energy consumption in both the industrial sectors in general and the transport sector in particular. FECs in the "Other" sector (agriculture, residential and commercial construction) show a mixed situation, with generally small values variations between 2019 and 2020. In terms of long-term trends, 24 Member States have reduced their level of FEC from 2005 to the present and all, only one state (Poland) have reduced their PEC. The largest percentage decline was in countries such as Spain, Italy and Greece, where the FEC and PEC recorded 20% lower annual values in 2020 than in 2005.

The values set as targets and the evolution towards their achievement vary greatly from one state to another. It is found that a number of 20 Member States have met their targets set for 2020 in terms of FEC, and Greece and Romania have largely met their targets in this area. There are also 7 Member States of the European Union that have not met their targets, of which Lithuania has the longest distance to the target (a 19% reduction compared to 2020 emissions). Also, in the case of the PEC, it is found that 3 member states of the European Union have not met their targets for 2020, of which Belgium is the one with the most unfavorable evolution in this field, exceeding by 3% the target set.

Considering that the share of 21.3% of energy consumed comes from renewable sources in 2020, it can be said unequivocally that the main target set for 2020 (20%) has been reached across the EU, according to the previous estimates by the SEE.

The success in this area is based on years of consistent work at the level of the Member State, even if the progress made in each country is different. Due to the COVID-19 pandemic, throughout 2020, there were exceptional circumstances, marked by instability in most economic sectors, which facilitated the achievement of the target set for renewable/sustainable energy by reducing total energy consumption. A continuous, accelerated and accentuated transformation of the systems for obtaining energies from sustainable/ecological sources will be necessary further in order to reach the fixed objective, of 32% of renewable energy, for 2030 (see Fig. 17).

As can be seen from the above, the increase in the use of energy from green sources (renewable/sustainable) has many benefits for society:

- mitigation and/or prevention of climate change;
- reduction and/or elimination of greenhouse emissions;
- improving energy security.

In this area, the EU has set two temporary benchmarks, namely to ensure that a level of 20% of final gross energy consumption in 2020 will come from green energy sources and that this percentage will continue to rise steadily to a level of 32%, in 2030.

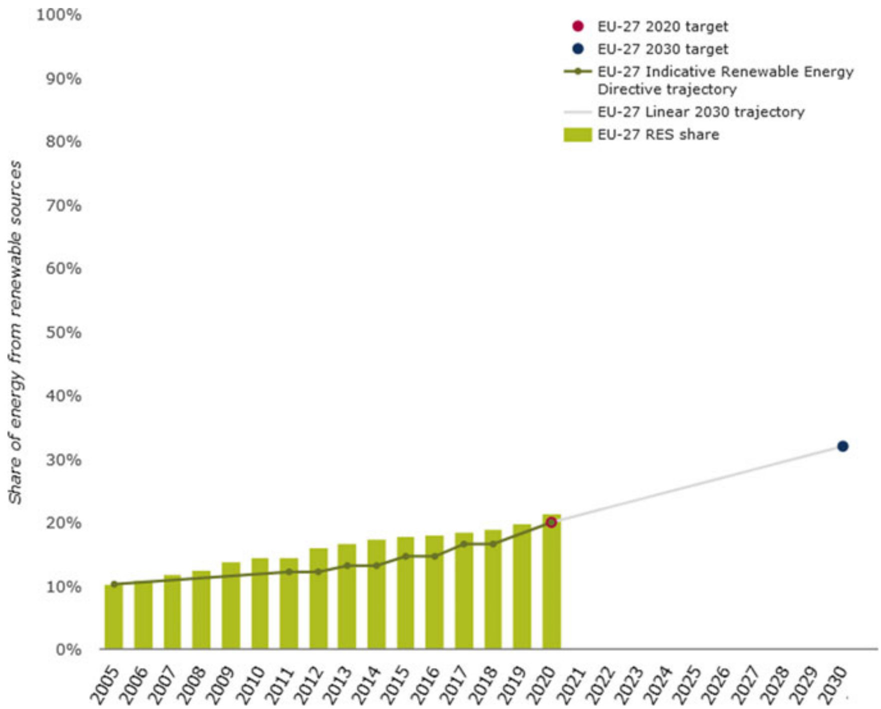


Fig. 17 Progress towards renewable energy. *Source* Targets since 2005, *source* https://www.eea.europa.eu

EU statistics show that the target for 2020 has been met, with renewable energy consumption rising annually from 19.7% of total gross final energy consumption in 2019 to 21.3% by 2020. Achieving this target has been made possible by the sustained increase in the production of electricity from renewable energy sources (RES), the percentage increasing from around 34% to a level of 37.3% in 2020. Also during this period, although At a much slower pace, the share of renewable energy used in transport activities and in the area of residential construction (space heating and cooling) has increased. Given that the share of RES depends essentially on total energy consumption, it is relevant to note that total gross final energy consumption decreased substantially between 2019 and 2020, by approximately 6%, due to the impact of measures to combat the effects of the Covid-19. Obtaining electricity from RES is a priority due to low operating costs and preferential shipping.

In line with long-term trends, the share of RES has increased by 200% between 2005 and 2020, determined by the application of policies and support schemes dedicated to obtaining energy from renewable/sustainable sources, as well as by increasing competitiveness. economic due to technical and technological progress. This situation amounted to an average annual increase of about 0.74%. This level of growth recorded in 2020 (1.6%) is the highest in the entire time series. Although it

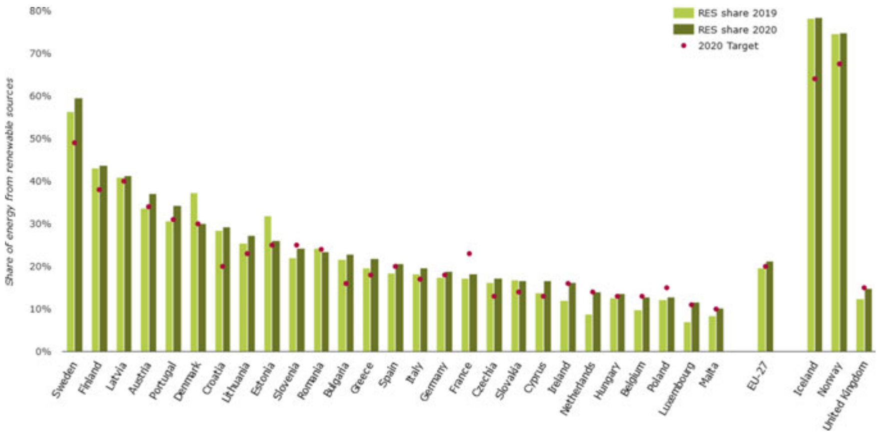


Fig. 18 Targets set by EU member states for renewable energy sources. *Source* https://www.eea.europa.eu/ims/share-of-energy-consumption-from

is found that the EU has reached its target for 2020, in terms of energy from renewable/sustainable sources, sustained action remains needed. There is a possibility that the impact caused by the COVID pandemic will be short-lived, in which case if no structural changes are undertaken, concrete actions and unprecedented transformations will be needed to reach the target of 32%, set for 2030. In addition, the EU Commission has recently proposed a major amendment to the Renewable Energy Directive, with a very ambitious goal of reducing pollutant emissions by 40% by 2030, paving the way for the 2050 target of "Zero Carbon" (Fig. 18).

As can be seen from previous EEA estimates, 23 of the total EU Member States (27) see an increase in the levels of use of energy from renewable/sustainable sources in 2019 compared to 2020. Of the 23 countries mentioned above, in countries such as the Netherlands, Ireland and Luxembourg have seen increases of more than 4% in the share of energy produced from renewable/sustainable sources in 2020. Although there have been increases in these three countries, other Member States such as Estonia and Denmark recorded a significant decrease in the share of energy obtained from renewable/sustainable sources compared to the level recorded in 2019. Ignoring the top countries with an increase in the use of renewable energy, countries such as Sweden, Austria and Portugal were the Member States that also recorded a significant increase in the share of RES, over 3% of total energy produced in 2020.

In order to be able to reach the target level set at EU (see Fig. 19), for the production of renewable/sustainable energy of around 20% by 2020, each country has made sustained efforts to achieve its own national target.

In conclusion, despite the economic turmoil caused by the Covid-19 pandemic, it can be stated that of all the methods of energy production, only the use of renewable sources has increased in 2020. The production of electricity from renewable/sustainable sources of recorded an increase of 7% (a record 500 TWh)—almost 20% higher than the average annual percentage increase recorded in 2010. The energy

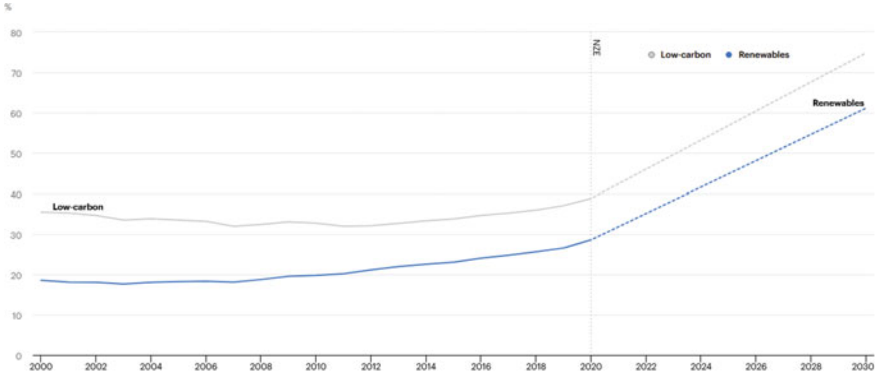


Fig. 19 Net zero scenario for 2020–2030. Renewable energy sources and the level of carbon emissions in energy generation. *Source* https://www.iea.org/reports/renewable-power

produced by the sun and wind accounted for about 1/3 of the total increase in 2020 of the production of electricity from renewable/sustainable sources and of the energy produced by water representing another 25%, and the rest from biofuels. The first annual decline in electricity demand since the 2008 financial crisis, combined with very large increases in solar and wind power generation capacity in 2020, led to a 2% increase in the share of renewable sources in total production. Electric power. The share of renewable sources in global energy production has reached the highest level of growth ever recorded, 28.6%, in 2020. To reach the target of "Net Zero", obtaining energy from renewable sources must increase annual of about 12% in the period between 2021 and 2030. Despite record increases in renewable energy production capacity, production growth has been still significantly below that set for 2020. It will take a very rapid implementation of all technologies to obtain energy through the use of renewable sources to put the world on the right track with the etNet Zero" emissions scenario by 2050.

5 Conclusions

Mankind has experienced several energy transitions over time as new resources have been discovered and the necessary inventions have been made to use them. Population growth, industrialization and urbanization have put pressure on the use of energy resources but have also generated environmental pollution. For this reason, we are currently witnessing a new energy transition that is clearly different from the others by its pace but also by the main force that animates it, namely public authorities and international institutions. This energy transition is the first process of this type that is politically driven and not generated by a natural evolution of the world economy and humanity. The reason for the need to adopt concerted solutions worldwide is taking into account the major risks that global warming can generate for humanity.

The energy transition offers solutions to protect the environment, but it generates economic, social, technical problems to which companies, public authorities, financial institutions and researchers must find answers. The need to protect the environment and the decrease of fossil fuel resources have generated a new energy transition, renewable energy being the new type of energy that will ensure the transition to a low carbon economy. The energy transition is accompanied by a complex process of changing the attitudes and behaviors of energy consumers, producers and investors. The consequences are profound not only from an economic and ecological point of view, but also socially, renewable energy being a solution for reducing energy poverty and developing rural communities. Changes in consumer attitudes and metamorphosis of business strategies are observable in all countries, the energy transition being a reality felt even in the financial sector. Adaptation but also innovation are the watchwords for all categories of stakeholders. The complexity of the energy transition phenomenon requires the involvement of companies, consumers, portfolio investors but also the educational system, which must encourage the change of mentalities and the improvement of behaviors. Decarbonising the European economy is a bold goal set by the European Green Pact, with the transition to clean energy being one of the most important directions for action in EU countries. Through concrete measures, EU countries aim at interconnecting energy systems and integrating renewable energy resources, increasing energy efficiency, green product design, combating energy poverty Access to affordable energy in a safe, sustainable and modern way (Sustainable Development Goal, SDG7) is the solution to combating energy poverty, a phenomenon that is manifesting in both developed and emerging economies.

Annex

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
High Income Countries													
Andorra		●	●						●			●	
Antigua and Barbuda	**E, P**	●											
Australia	**P, P*(N), T***	●	◖	●	◖	◖	●	●	●, ◖				●, ☆[6], ☆*
Austria	**E, P, HC(O), T**	●	●		●	☆		●		☆[6]	●		●[6], ◖
Bahamas, The	**E, P**	●											
Bahrain	**E, P**	●	●		●			☆	●				●
Barbados1	**E, P**	●			●					●			●
Belgium	**E, E*, P(O), P*(O), HC, T**	●		◖	◖	☆		●	●	●	●		◖
Brunei Darussalam	**E**	●											
Canada	**P***	●	◖	◖	◖	●, ◖, ☆*		☆	◖	●[6], ☆	●[6]		●, ☆[6,7], ★*7
Chile	**P**	●	●	●	●			●	●, ○	●[6]	●[6]		●, ☆[6]
Croatia	**E, P(O), HC(O), T**	●	●[6]			☆			○			★	●[6]
Cyprus	**E(N), P(O), HC(O), T(N)**	●	●		●	☆			●				●

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Czech Republic	**E, P(O), HC(O), T**	●	●			●		●		●[6]	●		●[6]
Denmark	**E, P(N), HC(O), T(O)**	●	●[6]		●	☆	●[6,9]	●	●, ○	●[6]	●		●[6], ★
Estonia	**E, P, HC, T**	●	●			☆			●, ○			●	●, ☆[6]
Finland	**E, P(O), HC(O), T**	●	●			☆		●	●	★[6], ●[7]		●	●[6], ★
France	**E, P(N), HC, T**	●	☆			☆	●	●	●, ○	●[6]	●[6]	☆	☆[6]
Germany	**E, P(N), HC(O), T**	●	●			●	●[9]	●	●, ○	●	●		●[6], ★
Greece	**E, HC(O), P, T**	●	●	●	●	☆	●[8]	●	●	●[6]	●		●, ☆[6], ★
Hungary	**E(N), P(N), HC(O), T(N)**	●	●		●	☆			●, ○	●			●
Iceland	**E(O), T(O), HC(O), P(O)**	●											
Ireland	**E, P(N), HC(O), T(O)**	●	●			☆	●[8]	●	●	★[6]			☆[6,7]
Israel	**E(N), P(N), T**	●	●	●	●		●		●, ○	●[6]			●, ★
Italy	**E, P, HC(O), T**	●	●		●	☆			●, ○	●	●[6]		●[6,7], ★*, ★
Japan	**E, P**	●	☆					●	●, ○	●		☆	●, ☆[6]

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Korea, Republic of	**E, P**	●		●	●	●	●	●		★	●	●	●[6]
Kuwait	**P**	●							●				
Latvia	**E(N), P(O), HC(O), T(N)**	●	●		●	☆			●	●			
Liechtenstein		●	●										
Lithuania	**E, P, HC, T(O)**	●	●[6]	●	●	☆	●[6]		●, ○	●[6]			●, ★[6]
Luxembourg	**E, P(O), HC, T**	●	●			☆			●, ○				●, ☆[6]
Malta	**E, P(O), HC(O), T**	●	●		●	☆			●	●			●[6]
Mauritius	**P**	●			●				●	●			●[6]
Monaco		●											
Nauru		●											
Netherlands	**E, P(O), HC, T(O)**	●	●[6]		●	☆	●[8]	●	●	★[6]	●[6]	●	●[6], ☆, ★
New Zealand	**P**	●			◖	●				☆			●
Norway	**E(O), P(O), T(O), HC(O)**	●		●		●[7]	●[9]	●	●	●			●[6]
Oman	**P(N)**	●							●				
Palau	**E(O), P**	●		●									

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Panama	**E**	●	●		●	●			●	●	●	●	
Poland	**E, P, HC(O), T**	●	●	●		☆		●	●, ○	●			●[6], ★
Portugal[2]	**E, P, HC(O), T(N)**	●		●		☆	●	●	●, ○	●			●, ☆[6]
Qatar	**P**	●							●				
Romania	**E(N), P(O), HC(N), T(N)**	●		●	☆	☆		●					●[6]
San Marino		●	●										
Saudi Arabia	**P**	●			●, ☆				●				
Seychelles	**E, P**	●			●				●	●	●		●
Singapore	**P(O)**	●			●				●				●
Slovak Republic	**E, P(O), HC(O), T**	●	●			☆		●	○	●[7]			●[6]
Slovenia	**E(N), P(O), HC(N), T(N)**	●			●	☆		●	●	●	●		●[6]
Spain[3]	**E(N), P(N), HC(O), T(N)**	●			☆	☆	●		●, ○	★	●	●	●[6], ★
St. Kitts and Nevis		●											
Sweden	**E(N), P, HC(O), T(O)**	●		●		○		●		●	●		●

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Switzerland	**P**	●	●					●		●		☆	●[6]
Taipei, China	**P**	n/a	●			●					☆		
Trinidad and Tobago	**P**	●								●	●		
United Arab Emirates	**P, P*(O)**	●		◖	☆*				●, ◐			◖	◖
United Kingdom	**E(O), P(N), P*(O), T(N), HC(O)**	●	◖	●		☆	●[8]	●	●, ◖	●		●	●[6], ☆[7], ★, ★*
United States	**T(N), P*(N)**	●	◖	☆*	☆*	◖, ☆	●, ◖[9]	◖	●, ◐	●	●[7], ◖[7], ★, ★*		●[6], ☆[7], ★*
Uruguay		●			●	●	●		●	●		●	●[6]

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Upper-Middle Income Countries													
Albania	**E, T(O)**	●	●	●	●	●		●	●, ○	●	●	●	●
Argentina	**E, P**	●	●	●	●	●			●	●[6]	●[6]	●	●, ☆[6]
Armenia	**E, P**	●	●		●				●				●[6]
Azerbaijan	**P(N)**	●											●
Belarus	**P**	●	●	●						●			●
Belize	**P**	●							●				
Bosnia and Herzegovina	**E(O), HC(O), T(O), P**	●	●						●				
Botswana	**P**	●			☆				●, ○	●			●
Brazil	**P.T**	●			●	☆			●	●	●		●
Bulgaria	**E, P(N), HC, T(N)**	●	●			☆							
China	**E(N), P(N), HC(O),T(O)**	●	●	☆		☆	●		◖, ●[7]	●	●	●, ◍	●, ★[6,7], ◍
Colombia	**E, P**	●				●			●, ○	●	●		●
Costa Rica	**P**	●			●	●			●	●[6]			
Cuba	**P**	●											

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Dominica		•											
Dominican Republic	E, P	•			•				•	•	•		•
Ecuador		•	•			•			•	•			•
Equatorial Guinea		•											
Fiji	E, P	•								•	•		
Gabon	E, P	•											
Georgia	E	•											•[6],
Grenada	P	•			•					•			
Guatemala	P	•			•	•			•	•	•		
Guyana	P	•								•			
Indonesia	E, P, T	•	•	•		•			•	•	•		•
Iran	P(O)	•	•							★	•	•	•
Iraq	P(O)	•							•				
Jamaica	P	•			•	•			•, ○	•	•		
Jordan	E, P, HC(O)	•	•		•		•		•	•			•, ★[6]
Kazakhstan	P	•	•					•	•				•

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Kosovo	**E(O), P(O), HC(O)**	n/a	•										
Lebanon	**E, P(O), HC**	•			•				•	•[6]			•[6]
Libya	**E, P, HC(O)**	X								•			
Macedonia, North	**E, P, HC(O), T(O)**	•	•							•[6]			•[6]
Malaysia	**P, HC(O), T(O)**	•	•	•	☆	•			•	•			•
Maldives	**E, P(O)**	•	•						•				
Marshall Islands	**E, P(O)**	•								•			
Mexico	**E(O), P(O), HC, T(O)**	X			•	☆			•	★	•		•, ☆[6], ★
Montenegro	**E(O), P(O), HC(O), T(O)**	•	•						•	★			
Namibia	**P**	•					•						
Paraguay	**T(N)**	•				•				•			
Peru		X	•	•	•	•			•	•			•
Russian Federation	**E(O), P**	•	•						•				•

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Samoa	**E**	●											
Serbia	**E(O), P, HC(O), T(O)**	X	●										●
South Africa	**P**	●		●		●	●		●	●			●[6]
St. Lucia	**P**	●			●								
St. Vincent and the Grenadines[1]	**P(O)**	●			●								
Suriname	**P**	●			●				●				
Thailand	**E, P, HC, T**	●	●		●	●				●		●	☆, ●[6], ★[7]
Tonga	**P**	●							●				
Turkey	**P, HC**	●			●	●	●[6]		●, ○			☆	●[6]
Turkmenistan		●											
Tuvalu	**E, P(O)**	●											
Venezuela		●											

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
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Lower-Middle Income Countries													
Algeria	**P**	•	•						•			•	•
Angola	**P**	•	•			•							•
Bangladesh	**E, P(N)**	•							•	•			•, ★
Benin	**E, P**	•							•				
Bhutan	**E, P,HC**	•							○				
Bolivia	**P**	•	•	•	•				•	•		•	•
Cabo Verde	**P**	•			•				•	★	•	•	
Cambodia	**E**	•							•				
Cameroon	**P**	•								•			
Comoros	**E, P**	•											
Congo, Republic of	**P**	•											
Cote d'Ivoire	**P**	•							•	•			
Djibouti	**E, P**	•											
Egypt	**E, P**	•	•		•				•	•[6]			•
El Salvador		•							•	•	•	•	•
Eswatini	**P**	•							•				

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Ghana	**P**	●	●	●	●	●		●	●	●			●
Honduras	**E, P**	●	●		●				●	●	●		
India	**E, P, P*, HC, T**	●	◖	●	◖, ★*	●		●	●, ○, ◑	●	●	●, ◖	●[6], ★[7*]
Kenya	**E, P, HC**	●	●			●			●	●		●	●
Kiribati	**E, P**	●											
Kyrgyzstan		X		●							●		●
Lao PDR	**E**	●											
Lesotho	**P**	●			●				●	★	●	●	●
Mauritania	**E(O), P(O)**	●											
Micronesia, Federated States of	**E(O), P(O)**	●			◖								
Moldova	**E(O), P(O), HC(O), T(O)**	●	●		●				●				●
Mongolia	**E, P**	●	●						●, ○	●			
Morocco	**P, HC(O)**	●			●				●				●[6]
Myanmar	**P**	●							○	●			
Nepal	**E(O), P**	●	●					●	●	●	●		●
Nicaragua	**P**	●	●							●	●		●
Nigeria	**P(N)**	●	●	●					●	●			●

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Pakistan	**E, P(N)**	●	●		●			●		●			●
Palestine, State of [5]	**E, P(O)**	●	●		●				●	●			
Papua New Guinea	**E, P**	●											
Philippines	**E, P**	●	☆	●	●	●			○	●	●	●	●[6], ★[76]
Sao Tome and Principe	**P**	●											
Senegal	**P**	●	●	●	●				●	●			
Solomon Islands	**E, P**	●											
Sri Lanka	**P(N), T(O)**	●	●	●	●	●			●	●		●	●
Tanzania	**E, P**	●											
Timor-Leste	**E, P**	●											
Tunisia	**E, P**	●			☆				●,○	●			●[6]
Ukraine	**E, P(O), HC(O), T(O)**	●	☆		●	●				●		☆	●[6]
Uzbekistan	**E, P(N)**	●							●,○		☆		
Vanuatu	**E, P**	●	●		●					●			
Vietnam	**E(N), P(N), T**	●	☆	●	●	●		●	●,○	●	●	☆	●
Zambia		●	●						●	●			●

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Zimbabwe	**T(N), P**	●			★	●			●○	●		●	●

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Lowe Income Countries													
Afghanistan	**E, P**	●							●				
Burkina Faso	**E, P**	●							●	●	●	●	
Burundi	**E, P**	●											
Central African Republic	**P**	●											
Chad	**P**	●											

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies							Fiscal Incentives and Public Financing			
			Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Congo, Democratic Republic of	**E, P**	•											
Eritrea	**P**	•											
Ethiopia	**E, P**	×				•			•				
Gambia	**E, P**	•							•	•			
Guinea	**E, P**	•								•			
Guinea-Bissau	**E, P**	•							•				
Haiti	**E, P**	•											•
Korea, Democratic People's Republic		•											
Liberia	**E, P, T**	•								•			
Madagascar	**E, P**	•							•	•			
Malawi	**E, P, HC**	•				•	•		•	•			•
Mali	**E, P**	•							•	★			•
Mozambique	**P, HC, T**	•				•			○	•			•
Niger	**E, P(O)**	•							•	•			
Rwanda	**E**	•	•						•	•	•		•
Sierra Leone	**P, HC**	•											

Country	Renewable energy targets	Renewable energy in INDC or NDC	Regulatory Policies: Feed-in tariff/premium payment	Electric utility quota obligation/RPS	Net metering/billing	Biofuel blend, renewable transport ligation/mandate	Renewable heat obligation/ mandate, heat feed-in tariff, fossil fuel ban for heating	Tradable REC	Tendering	Fiscal Incentives and Public Financing: Reductions in sales, energy, CO_2, VAT or other taxes	Investment or production tax credits	Energy production payment	Public investment, loans, grants, capital subsidies or rebates
Somalia	**P**	●											
South Sudan	**E, P**	X											
Sudan	**E, P**	●				●							
Syria	**P**	●	●		●				●	●	●		
Tajikistan	**P(O)**	●	●							●			●
Togo	**E, P(O)**	●								●			
Uganda	**P**	●	●						●	☆			●
Yemen	**E(O), P, T(O), HC(O)**	●											

E	Energy (final or primary)	★	New (one or more policies of this type)	●	Existing national policy or tender framework (could include sub-national
P	Power	★*	New sub-national		
HC	Heating or cooling	☆	Revised (from previously existing)	◖	Existing sub-national policy or tender framework (but no national)
T	Transport	☆*	Revised sub-national		
*	Indicates sub-national target	●	Removed	○	National tender held in 2020
(R)	Revised			◐	Sub-national tender held in 2020
(N)	New				

(O) Removed or came to term

Renewable energy not included in NDC

[1] In some Caribbean countries, differentiated metering and grid supply policies have been adopted that allow household consumers to offset energy, while industrial consumers are required to supply 100% of the energy generated in the grid. These types of policies are materialized in GSR net metering solutions.

[2] FIT support removed for large-scale power plants.

[3] Spain removed FIT support for new projects in 2012. Support remains for certain installations linked to this previous scheme.

[4] At the U.S. level, statewide policies include RPS policies.

[5] In the classification of the countries, made by the World Bank, the Palestinian state is referred to as the "West Sea and Gaza".

[6] Also included are heating and / or cooling technologies that use renewable energy sources.

[7] Aviation, maritime or rail transport 8 Heat FIT

[9] Fossil fuel heating ban

Note: Countries are organized according to annual gross national income (GNI) per capita levels as follows: ″high″ is USD 12,536 or more, ″upper-middle″ is USD 4,046 to USD 12,535, ″lower-middle″ is USD 1,036 to USD 4,045 and ″low″ is USD 1,035 or less. Per capita income levels and group classifications from World Bank, ″Country and lending groups″, http://data.worldbank.org/about/country-and-lending-groups, viewed May 2021. Only the adopted policies are mentioned in the table; for some of the policies presented, some of the implementing regulations may not yet be sufficiently developed or ineffective, leading to a lack of implementation or impact. Also, policies that are known to be discontinued have been omitted and those that have been removed or expired have been marked. Many of the policies on access to energy sources are limited by the scope of the technology.

Source: REN21 Policy Database. See GSR 2021 Data Pack at www.ren21.net/gsr-2021.

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Renewable Energy as a Promising Venue for China-Russia Collaboration

Vasilii Erokhin and Gao Tianming

Abstract China is acknowledged as a leader in establishing new energy generation capacities. The most rapidly growing renewable energy sectors have been hydropower, wind and solar energy, and biofuels. According to the strategic development objectives set by China's government, renewable sources' portion in the energy sector will continue increasing. Russia also enjoys a striking potential in renewables' development, not only natural resources but also technologies and experience. In the 1930s, the Soviet Union first-ever built wind generators. In the 1960s, it installed the world's first geothermal power plants. However, the abundant availability of hydrocarbons has predetermined Russia's energy sector growth on the basis of fossil fuels and coal. Today, alternative sources contribute about 1% of Russia's energy balance. China is particularly interested in expanding energy generation for domestic needs, which makes cooperation with Russia in the Far East and Siberia attractive for Chinese investors. This chapter aims to investigate the opportunities for converging the experience, technical capabilities, resource potential, and economic resources of the two countries to diversify their energy-related industries away from fossils in favor of renewable energy.

Keywords Biofuels · Fossil fuels · Hydropower · Renewable energy

1 Introduction

Amid progressing climate change and the volatility of the global energy market, renewable energy generation has been increasing steadily (Gernaat et al. 2021). Many scholars (Bansal et al. 2005; Khambalkar et al. 2010; Obichere and Olubiwe 2013; Lundy 2019) and the international expert community in general (Intergovernmental Panel on Climate Change 2021; United Nations Framework Convention on Climate Change 2018; Rio Tinto 2020) recognize the need to respond to climate change through energy conservation, improving the productivity of energy use, and

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eliminating fossil fuels. The key renewable energy sectors are hydropower, wind energy, solar energy, as well as other sources, including geothermal and ocean energy and biofuels (Khazova 2019). The generation of electricity and energy from all kinds of renewable sources is still associated with carbon emission due to manufacturing processes, but the embedded carbon of solar or wind energy is radically lower compared to traditional sources, such as coal (5.0% and 1.5% compared to 76.0%. respectively) (Sayigh 2021). Therefore, shifting to renewable energy is believed to become one of the solutions for reducing the greenhouse effect and thereby tackling climate change (Ellabban et al. 2014).

In some countries, energy from renewable sources is becoming an increasingly important part of the energy balance, especially in the electric power industry. The topic of alternative or green energy is often associated in the popular consciousness with developed countries of Europe of North America, where environmental legislation is being developed, and comprehensive measures are being implemented to transfer the energy sector to low-carbon, low-emission, and environmentally-friendly technologies. Meanwhile, rapidly industrializing countries like China prominently feature the global renewable energy shift. The share of the renewable sector in China's energy mix has been growing since the early 2000s, especially rapidly in recent years. It is expected that by 2030, at least 15% of energy generation in China will come from renewable sources. Today, China is the world's biggest investor in expanding renewable energy facilities and producing power from renewable sources, such as hydropower, solar and wind power, and biofuels (Aliev and Zakharcheva 2017; Aliev and Avramenko 2017). According to Xu et al. (2021), China's total renewable energy capacity amounted to 794 million kW in 2020 (39.5% of the country's overall energy generation capacity). The replacement role of renewables in the energy mix has become increasingly prominent.

For China, there are several reasons for such purposeful efforts to develop the renewable energy sector. China's phenomenal economic growth for over four past decades required a radical increase in energy supply. Until recently, the latter was provided by coal (70% of total energy supply) and oil (18%, respectively) (Salygin et al. 2015). Coal is one of the environmentally dirtiest types of fuel. Its combustion releases 1.5 times more carbon dioxide (CO_2) compared to that of oil. With such a high level of coal consumption, China has not only faced severe environmental problems, but has also experienced tremendous CO_2 emission (about 30% of the total emission on the planet) (Zheng et al. 2020; Turnbull et al. 2016). CO_2 emissions are believed to be the significant contributing factor of climate change globally (Lin et al. 2020; Muhammed and Tekbiyik-Ersoy 2020). Global warming is increasingly considered a real threat to China's largest coastal cities (Shanghai, Hong Kong, etc.). Moreover, climate change is associated with increased frequency and intensity of droughts in the northern provinces and floods in the south. Annual loss due to air pollution from the combustion of fossil fuels alone amounts to about $900 billion (Mastepanov 2020).

In pursuance of reducing environmental costs and pollution, China's government is making attempts to diversify energy sources. National energy policy has been changing in accordance with both the economic growth trajectory of the country and the influence of external factors—globalization of the energy market and the global awareness of the climate change impacts (Mastepanov 2019). Renewable energy is expected to become the intrinsic element of China's energy supply within the next decade. Considering the size of China's economy and the volume of energy consumption, this will become a factor of uncertainty for the entire global energy market (Mastepanov 2020). For example, in 2021, China's post-pandemic return to economic growth has dramatically increased the country's consumption of fossil fuels (Myllyvirta 2021), causing spikes in oil and gas prices globally and the energy deficit in China. The surge of China's CO_2 emissions by 4% in 2020 was caused by stimulating the dirtiest and most energy-intensive sectors, such as construction and heavy manufacturing.

In this regard, the question arises—how sustainable can the movement towards the low-carbon energy sector be in such resource-abundant countries like China? How strong is the economic factors' effect on restructuring the energy sector? As demonstrated by Xu et al. (2018) and Remizova (2017), the development of the renewable energy sector could not benefit some countries in light of the abundance of cheap and readily available fossil fuel reserves. In this sense, Russia, one of the world's biggest exporters of oil, gas, and coal and a supplier of cheap fossil fuels to China, could serve as a demonstrative example of such a resource-abundant country. Russia has a huge potential in the development of renewable energy. The country's first hydroelectric power station was established back in 1892. The Soviet Union created the world's first wind power generators in the 1930s and geothermal power facilities in the 1960s (Avramenko and Baiguskarova 2018). But primarily due to the abundance of conventional fossils, economic incentives in the renewables sector in Russia have remained poor. Currently, renewables contribute only 1% to the country's total electricity generation. The Russia-China links in various spheres have increasingly tightened in recent years, but hardly in the sphere of energy. Such megaprojects as the Power of Siberia gas pipeline and the supply of liquefied natural gas (LNG) from the Russian Arctic and coal from the Urals and the Far East indicate Russia's increased focus on the supply of fossil fuels to China. In the future, such growing interchangeability of the two countries' energy sectors may not only affect global energy markets, but also turn into an economic obstacle to developing the renewable sector. In addition to the increasing physical interconnectedness of the energy systems of Russia and China, there is also an apparent economic dilemma. Low global oil and gas prices encourage China to increase consumption of cheap energy, thereby slowing the reduction of CO_2 emissions. In contrast, high global prices encourage Russia to increase supplies to the world market and not pay attention to the development of renewable energy technologies. In this chapter, we attempt to explore the opportunities for the two countries to spur collaboration in renewable energy and thereby reduce the long-term dependence on fossil fuels in their energy mix. The study is performed based on data from 2000 to 2020 for such sectors as hydropower, wind energy, and solar energy. Other types of power generation (biofuel, ocean, and geothermal energy) are also considered.

2 Renewable Energy in China and Russia: Comparative Analysis

2.1 Overview

The share of primary energy from renewable sources is one of the core parameters to characterize the contribution of renewables to the country's total energy balance. As noted above, the importance of renewables in the global energy mix has been steadily increasing for over two past decades. However, in China and Russia, the growth rates of this sector are radically different. Since the 2000s, China has doubled the share of primary energy from renewable sources (although with significant year-to-year fluctuations, which is typical for the renewable energy sector, where power generation largely depends on weather conditions). Since 2014, the renewables' portion in China's energy balance has exceeded the global average (Fig. 1). The total volume of energy production from renewable sources approached 7,500 TWh in 2020, more than 2.5 times higher than in 2000. Although the bulk of energy supply is still provided by coal-fired thermal power plants (over 60% of the total energy generation), there has been happening the transformation of the structure of the energy sector. The average annual growth rate of the power industry amounted to 21% in 2000–2020, while that in the renewable energy sector reached 30%. The increase in the generation is mainly provided by emerging energy sectors, such as solar and wind power. The latter's portion in the renewable energy balance went up from a negligible 0.27% in 2000 to 21.08% in 2020 (solar energy—from 0.01% to

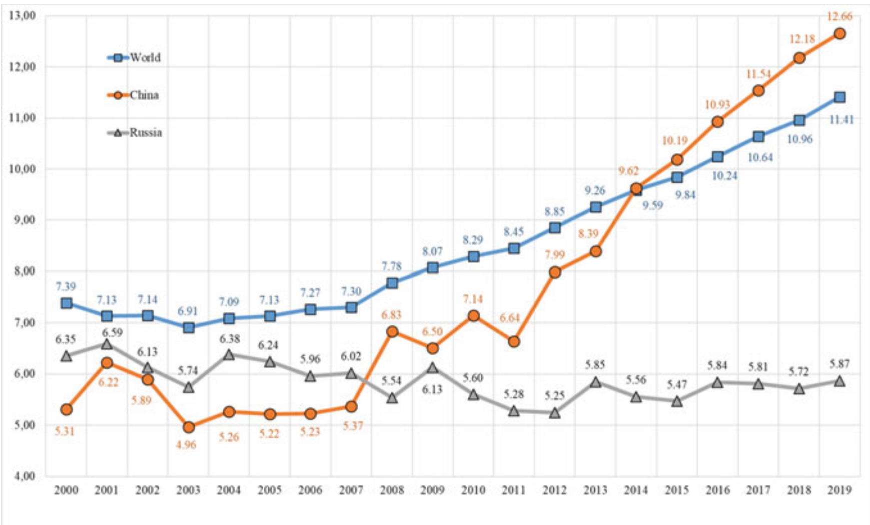

Fig. 1 Share of primary energy from renewable sources in China, Russia, and the world in 2000–2019, %. *Source* Authors' development based on Ritchie and Roser (2020)

11.80%, respectively). The role of hydropower, an indispensable source of energy a few years ago, has declined by more than a third since the early 2000s.

Unlike in China, there have been no significant changes in the renewable energy sector in Russia over the past two decades. The share of primary energy from renewable sources has fluctuated around 6% (declined from 6.35% in 2000 to 5.87% in 2020). As regards its hydropower potential, Russia is one of the world leaders. This determines the dominant role of hydropower in generating energy. The overwhelming amount of power is produced by large hydroelectric power plants located on the largest Russian rivers in Siberia, the Urals, and the central part of the country. The hydropower's portion in the renewable energy balance decreased slightly to 96.89% in 2020 (Table 1).

2.2 Hydropower

To varying degrees, in both countries, hydropower makes the greatest contribution to the total volume of renewable energy generation (Khazova 2019; Huang and Yan 2009). About 17% of power generation in the world accrue to hydropower (58% of renewable energy). In 2020, the installed capacity of hydropower facilities reached 1,330 GW (China's and Russia's portions in the total to be 29% and 4%, respectively). In 2020, the hydropower sector produced 4,355 TWh of energy, an equivalent to the annual electricity consumption in the United States. Over 31% of hydropower was produced in China, while Russia's portion amounted to less than 5% (Fig. 2).

China ranks first in the world in terms of electricity generation at hydroelectric power plants, the number of which has exceeded 45,000. Mastepanov (2019) estimates the gross hydropower potential of China to be 6,083 TWh/year, which means China currently uses only one-fifth of its overall capacity. At the same time, per capita parameters of electricity generation and energy consumption from hydropower in China are lower than those in Russia (Table 2). The degree of development of Russia's hydropower potential is much lower than that in China. In Russia, there are 104 hydroelectric power plants (52.3 GW in total) and about 90 small (less than 10 MW) hydroelectric power plants (0.15 GW in total). About one-fifth of the country's total energy generation capacity is accounted for hydropower.

2.3 Wind Energy

The potentials of both wind and solar energy are also significant. Sparsely populated coastal areas in Russia's North and the Far East are among the world's best spots for developing wind energy. In many other territories, wind potential allows power plants to operate with an annual capacity utilization (CUF) above 30% (northwest and south of Russia). In contrast, in China, CUF is much lower than the normative level used in the renewable energy program in Russia (21.3% and 27.0%, respectively) (Sidorovich

Table 1 Renewable energy generation by source in China, Russia, and the world in 2000–2020

Country/year	Total renewable energy generation, TWh	Hydropower		Wind energy		Solar energy		Other renewables	
		TWh	%[a]	TWh	%*	TWh	%[a]	TWh	%[a]
World									
2000	2,863.21	2,610.87	91.18	31.48	1.10	1.07	0.04	219.79	7.68
2005	3,272.09	2,883.30	88.11	104.69	3.20	3.84	0.12	280.26	8.57
2010	4,168.71	3,385.72	81.22	346.47	8.31	30.52	0.73	406.00	9.74
2015	5,506.49	3,864.43	70.18	828.65	15.05	254.67	4.62	558.74	10.15
2020	7,492.51	4,355.04	58.13	1,590.19	21.22	844.39	11.27	702.89	9.38
China									
2000	223.24	220.19	98.64	0.61	0.27	0.02	0.01	2.42	1.08
2005	397.67	393.05	98.84	2.03	0.51	0.07	0.02	2.52	0.63
2010	752.45	686.74	91.27	49.40	6.57	0.10	0.01	16.21	2.15
2015	1,391.80	1,112.70	79.94	185.60	13.34	39.50	2.84	54.00	3.88
2020	2,212.54	1,355.20	61.26	466.50	21.08	261.10	11.80	129.74	5.86
Russia									
2000	165.05	162.44	98.41	0.01	0.01	0.00	0.00	2.60	1.58
2005	174.01	170.95	98.24	0.01	0.01	0.00	0.00	3.05	1.75
2010	168.11	164.82	98.04	0.01	0.01	0.00	0.00	3.28	1.95
2015	170.08	166.31	97.78	0.15	0.09	0.34	0.20	3.28	1.93
2020	216.28	209.54	96.89	1.34	0.62	1.67	0.77	3.73	1.72

Note [a] Share in the total renewable energy generation
Source Authors' development based on Ritchie and Roser (2020)

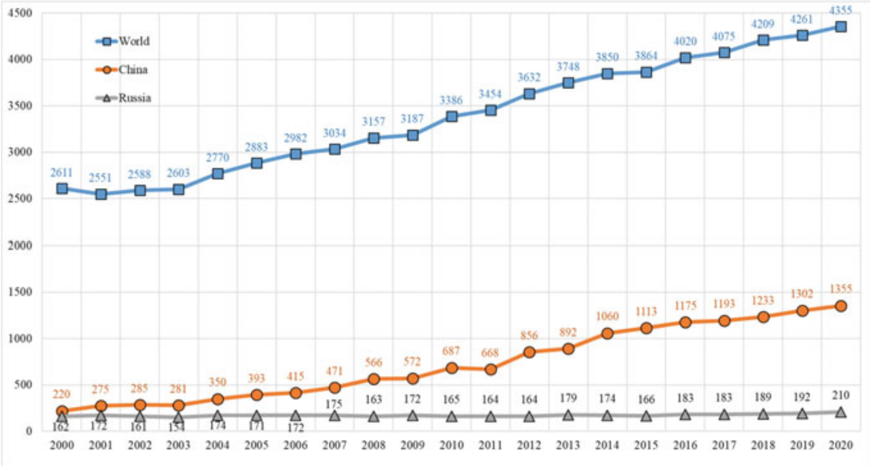

Fig. 2 Hydropower generation in China, Russia, and the world in 2000–2020, TWh. *Source* Authors' development based on Ritchie and Roser (2020)

2020). Meanwhile, the contribution of wind power to the energy mix in Russia is only 0.62% compared to 21.08% in China. Russia produces an incomparably smaller volume of energy from wind than China (1.34 TWh and 466.50 TWh, respectively). Since the early 2000s, China's role in the global generation of power from wind has increased from 1.94% to 29.34% in 2020. Russia's share has not exceeded 0.10% (Fig. 3).

Having comparable potentials for the development of wind energy, China and Russia use it differently. In light of the fairly cheap generation of energy from fossil fuels, wind power in Russia is developing slowly. The Russian market is not attractive for foreign companies because of its small volume. Nevertheless, the interest may grow in the future due to the fact that Russia remains a promising location for wind generation. Few of those remain relatively free for competition today. In Russia, Chinese companies could participate in developing the wind power sector, especially since Russia depends on foreign equipment and technologies in this area.

In China, all major parameters of the wind energy sector significantly exceed those in Russia, including per capita values, contributions of wind power in the total energy balance, and power consumption from wind (Table 3). According to the Energy Research Institute (2015), the total wind generation capacity is expected to grow tenfold by 2050 compared to today's level. However, despite such a rapid growth of installed capacity, its distribution across the country is uneven. Thus, more than 28% of the total installed capacity is concentrated in the northern provinces. On the one hand, this establishes an excellent opportunity for collaboration with Russia (for instance, integrating wind energy facilities in cross-border territories in a single network or establishing joint enterprises). On the other hand, northern provinces consume only about 6.78% of China's total energy supply, which means that extra energy could not be demanded locally. Southern provinces consume 20.5%

Table 2 Major parameters of the hydropower sector in China, Russia, and the world in 2000–2020

Country/year	Electricity generation from hydropower, kWh per capita	Energy consumption from hydropower, kWh per capita	Primary energy consumption from hydropower, TWh	Share of primary energy from hydroelectric power, %	Share of electricity production from hydropower, %
World					
2000	425	1,199	7,367	6.72	17.67
2005	441	1,199	7,845	6.18	16.47
2010	487	1,288	8,958	6.37	16.29
2015	524	1,332	9,827	6.51	16.58
2020	559	1,355	10,455	6.45	16.85
China					
2000	171	479	618	5.24	16.69
2005	295	802	1,068	5.08	16.23
2010	502	1,355	1,855	6.40	16.25
2015	791	2,004	2,819	8.10	19.39
2020	942	2,193	3,144	7.99	17.78
Russia					
2000	1,109	3,113	456	6.35	19.53
2005	1,190	3,232	464	6.22	18.99
2010	1,149	3,025	434	5.58	16.79
2015	1,147	2,931	425	5.44	16.48
2020	1,436	3,300	481	5.81	20.44

Source Authors' development based on Our World in Data (2021)

of total energy resources. Only 4.7% of the installed wind power capacity is located in the south (Khazova 2019), but the transfer of energy from potential China-Russia enterprises in the north may substantially increase the cost and make wind energy non-competitive in the local markets. One of the problems is the low length and poor concentration of power grids. Some wind farms are being built away from power lines (Zakharov 2016).

2.4 Solar Energy

The geographical location of China makes it possible to effectively use about 67% of its territory for the placement of solar energy facilities (Khazova 2019). In many provinces, the annual solar radiation exceeds 1,750 kWh/m^2 and 2,200 h of sunlight per year (Liu et al. 2011). Due to the availability of significant solar resources, China

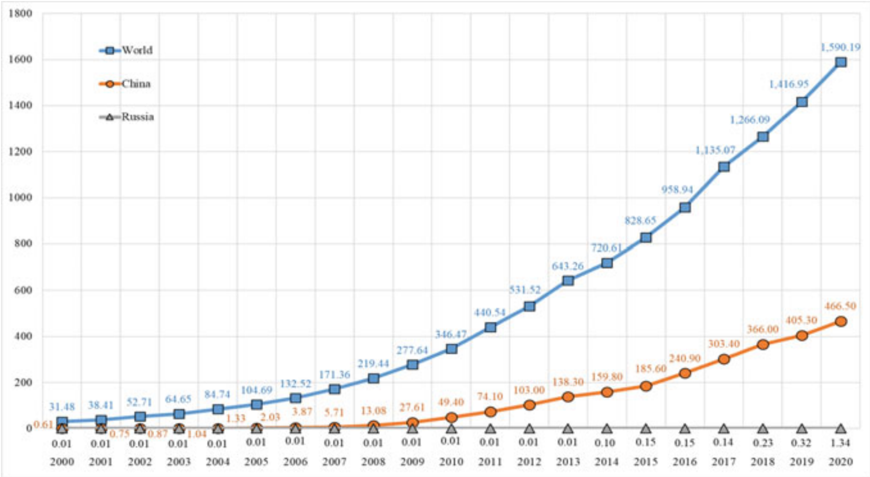

Fig. 3 Wind energy generation in China, Russia, and the world in 2000–2020, TWh. *Source* Authors' development based on Ritchie and Roser (2020)

has been demonstrating a rapid increase (50% per year) in the installed capacity of solar generation since the early 2010s. Since 2007, China has retained first place in the world in the production of solar panels. In 2011–2015, the government implemented various measures to boost solar energy generation, including direct subsidies for installing solar panels using photovoltaic converters (Mastepanov 2019). Due to these support measures, China's solar energy sector demonstrates steady growth from 0.1 TWh in 2010 to 261 TWh in 2020 (Fig. 4).

Russia cannot compete with China regarding the quality of solar resources. Major parameters of the solar energy sector in Russia are substantially lower than those in China (Table 4). Nevertheless, in some areas of the country, the solar generation capacity exceeds the global average. Thus, in Siberia and the Far East (Zabaikalsky Krai and the south of Primorsky Krai along the border with China), the capacity utilization factor for solar energy is 17%. Therefore, both solar and wind resources in the territories along Russia's border with China are more than sufficient for developing these sectors.

2.5 Other Renewables

The contribution of other sources to the total renewable power balance is low in China and negligible in Russia. China's biomass sector (0.7 billion tce) uses biogas made from industrial and municipal waste, livestock manure, energy crops, and firewood (Zhang et al. 2009). In Russia, the potential for developing the bioenergy sector is conditioned by the world's largest forest resources. Wood (firewood, sawdust,

Table 3 Major parameters of the wind energy sector in China, Russia, and the world in 2000–2020

Country/year	Electricity generation from wind, kWh per capita	Energy consumption from wind, kWh per capita	Primary energy consumption from wind, TWh	Share of primary energy from wind, %	Share of electricity production from wind, %
World					
2000	5	14	87.28	0.08	0.21
2005	16	43	279.98	0.22	0.60
2010	50	130	903.47	0.64	1.67
2015	112	285	2,103.67	1.39	3.55
2020	204	459	3,540.05	2.18	6.15
China					
2000	1	1	1.64	0.01	0.05
2005	2	4	5.24	0.03	0.08
2010	36	94	128.80	0.45	1.17
2015	132	334	469.50	1.35	3.23
2020	324	701	1,004.60	2.55	6.12
Russia					
2000	1	0	0.01	0.00	0.01
2005	1	0	0.02	0.00	0.01
2010	1	0	0.01	0.00	0.01
2015	1	3	0.37	0.01	0.01
2020	9	5	0.78	0.01	0.13

Source Authors' development based on Our World in Data (2021)

wood chips, shavings, bark, briquettes, pellets, etc.) is used to produce biofuels and generate bioenergy (Makarov and Aniskina 2018). Due to their energy efficiency and transportability, wood pellets are mainly demanded in the global market, including in China. Russia develops and builds biogas power plants of various capacities (including up to 10 MW) to produce both electric and thermal energy.

Since both Russia and China are maritime powers with extensive marine areas, ocean energy is a natural source of renewables for both countries (Quirapas et al. 2015; Bahaj 2011). The global ocean energy market is projected to grow to $107 million by 2025, up from $44 million in 2020. China's installed capacity of ocean energy resources has substantially increased from 20 GW in the early 2010s (Liu et al. 2011) to over 1,580 GW of offshore potentials in 2020 (Li and Ma 2020). In Russia, the most promising sites for ocean energy generation are located in the Bering Sea, the Sea of Okhotsk, and the Barents Seas. Therefore, in Russia, ocean energy has the greatest prospects for development in remote regions (the Far East, Chukotka, Arctic territories), where the installation of power transmission lines is complicated, while the supply of diesel fuel for power plants is expensive.

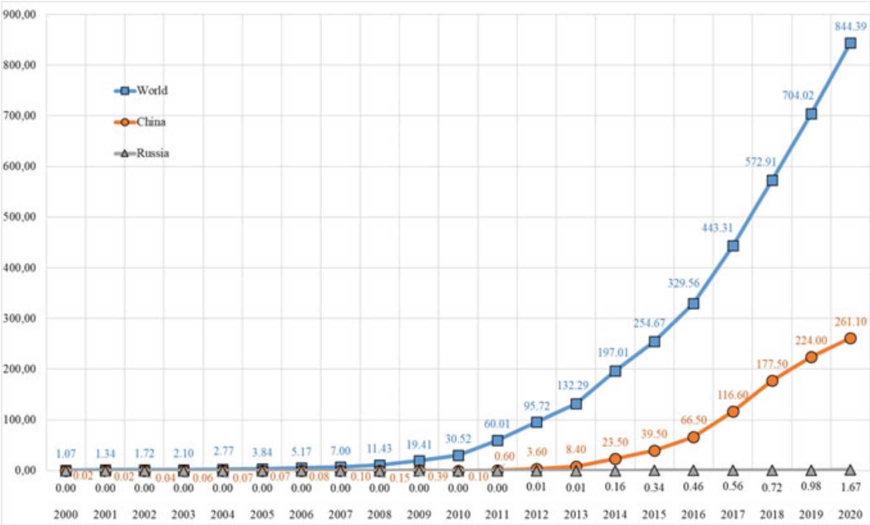

Fig. 4 Solar energy generation in China, Russia, and the world in 2000–2020, TWh. *Source* Authors' development based on Ritchie and Roser (2020)

The eastern regions of Russia bordering China (the Far East, the eastern sector of the Arctic zone of Russia, Sakhalin, the Kuril Islands) are also promising in developing geothermal energy (Butuzov 2019). In particular, in Kamchatka and the Kuril Islands, the power generation capacity of geothermal sources exceeds 2,000 MW, while thermal capacity amounts to 3,000 MW. In Kamchatka, geothermal resources allow for generating from 250 MW (eastern part of the peninsula) to 550 MW (central and northern parts). On Kunashir and Paramushir islands, geothermal reservoirs' potentials amount to 52 MW and 100 MW, respectively. In China, the potential of geothermal energy is substantially lower than in Russia, as well as lower as compared to China's wind and solar power capacity (Huang 2012; Zhu et al. 2015). Nevertheless, the potential untapped geothermal resources are estimated at 15% of the world's total (Hou et al. 2018). Promising spots are located in the Circum-Pacific and the Himalaya-Mediterranean tropical zones (Li et al. 1997) and East China (Zhu et al. 2015). In total, there are over 2,700 geothermal outcrops in China, but many of geothermal spots still need to be discovered, developed, and exploited (Hou et al. 2018; Zhao and Wan 2014).

Table 4 Major parameters of the solar energy sector in China, Russia, and the world in 2000–2020

Country/year	Electricity generation from solar, kWh per capita	Energy consumption from solar, kWh per capita	Primary energy consumption from solar, TWh	Share of primary energy from solar, %	Share of electricity production from solar, %
World					
2000	1	1	3.11	0.01	0.01
2005	1	2	11.21	0.01	0.02
2010	4	13	87.91	0.06	0.15
2015	35	88	649.74	0.43	1.09
2020	108	232	1,793.00	1.10	3.27
China					
2000	1	1	0.06	0.01	0.01
2005	1	1	0.23	0.01	0.01
2010	1	1	1.83	0.01	0.01
2015	28	71	99.88	0.29	0.69
2020	181	387	554.18	1.41	3.42
Russia					
2000	0	0	0.00	0.00	0.00
2005	0	0	0.00	0.00	0.00
2010	0	0	0.00	0.00	0.00
2015	2	6	0.85	0.01	0.03
2020	11	17	2.44	0.03	0.16

Source Authors' development based on Our World in Data (2021)

3 Regulatory Framework

3.1 Sustainable Development Approach

In an attempt to reduce the emission of CO_2 and greenhouse gases and tackle progressing climate change, developed and most of developing countries have been revising their development strategies to promote the green transition of their economies (Kokorin 2017; Nosko 2017). The green growth model assumes economic growth while ensuring the sustainability of natural assets, resources, and ecosystem services (Proskuryakova and Ermolenko 2017; Van 2014; Sadiku et al. 2019). The green growth approach uses a combination of economic and environmental tools. It has been integrated into all areas of public administration. The role of natural capital in economic growth is acknowledged by focusing on cost-effective solutions to mitigate environmental pressure and promoting the transition to new energy sources. In view of this approach, renewable power is considered an intrinsic part of the energy portfolio (United Nations Development Programme 2012; Frankfurt School—UNEP Collaborating Centre 2018; Somani and Koenig 2018) and a method to reduce waste and ensure economic sustainability (Sims 2003; Dincer 2000; Xu et al. 2018). In its Sustainable Development Goals (SDGs), the United Nations (UN) calls for integrating climate change mitigation policies into national agendas and promoting every possible development of the renewable power sectors at the national and international levels (United Nations 2021c). Two of the seventeen SDGs directly relate to energy, including renewable energy. Goal 7 assumes ensuring access to affordable, reliable, sustainable, and modern energy for all (United Nations 2021a), while Goal 13 envisages actions to combat climate change and its impacts (United Nations 2021b). One of the tasks aimed at achieving the SDGs is to lift the renewables' portion in the global power balance (Avramenko and Baiguskarova 2018). Another task is to improve inter-country collaboration to provide better access to renewables-related studies and innovations, such as new power sources, energy efficiency improvements, and environmentally-friendly use of fossil fuels (Aliev and Avramenko 2017).

The growing concern about developing renewable energy as a contributing factor of the overall sustainability is traditionally based on two circumstances: depletion of fossil fuel reserves and dependence of developed countries and rapidly growing developing economies on import of energy (primarily oil and gas) and a significant adverse environmental impact of fossils (Winzer 2012; Lucas et al. 2016). Recently, a third factor has taken on new significance—the desire to avoid dependence on price volatilities on the global energy market (for example, rises and falls on the oil market in recent years, the gas price crisis in September–October 2021 in Europe, etc.) (Galinis et al. 2020) and to protect the national economy from potential unilateral actions of energy suppliers or disruption of supply chains (for example, trade tensions between China and the USA, the Russia-EU and Russia-USA conflicts, transit of gas through Ukraine and new gas supply routes from Russia to Europe, the Russia-USA tension over Nord Stream 2, etc.). The access to energy and the degree of diversification of energy sources and energy generation capacities are becoming critical energy security parameters for any country (Karanina and Abasheva 2021; Esfahani et al. 2021). Such a tripartite sustainable development vision of the energy-related issues is now overwhelmingly shared by the international community, including China and Russia, the key actors in the global energy market.

3.2 China

Expanding renewable power solutions is among the core priorities of China's energy policy. The integration of renewable energy into the country's energy mix has been and remains a pivotal task for China's government (Khazova 2019). In 2014, President Xi Jinping featured the Four Reforms and One Cooperation energy strategy and outlined the quality growth trajectory of the power sector with Chinese characteristics in the new era (State Council Information Office of the People's Republic of China 2020). In the speech at the 41st group study session of the Political Bureau of the 18th CPC Central Committee, President Xi Jinping recognized the green development model to be an essential requirement of China's new development concepts (Xi 2017: 428). China "embraces the vision of a global community of shared future and accelerates its transformation towards green and low-carbon development in economy and society" (State Council Information Office of the People's Republic of China 2020) and aims to "speed up the building of … an industrial system for green, circular, and low-carbon development" (Xi 2017: 429). China is a proactive stakeholder in global energy governance. In September 2020, President Xi Jinping confirmed that China would continue implementing its Intended Nationally Determined Contributions by "adopting more vigorous policies and measures, striving to have carbon dioxide emissions peak before 2030 and to achieve carbon neutrality before 2060" (State Council Information Office of the People's Republic of China 2020).

China's contemporary energy policy took clear outlines in 2007, when the government released the first White Paper on Energy. That document articulated the basic principles that would guide strategic energy-related issues in the future (State Council Information Office of the People's Republic of China 2007). Those principles were further developed in China's Energy Policy 2012 (State Council Information Office of the People's Republic of China 2012) and the Energy Development Strategies Notice of Action Plan (2014–2020) (State Council Information Office of the People's Republic of China 2014), which both emphasized China's commitment to the low-carbon development agenda. The Action Plan (State Council Information Office of the People's Republic of China 2014) formulated five strategic tasks of the energy policy:

- improving energy security based on the effective use of "clean" coal, further growth of oil and gas sectors, promotion of renewable power, and establishment of an emergency reserve of power generation capacities and strategic reserves of oil;
- transformations in energy consumption—strict control over the use of energy, implementation of energy efficiency improvement plans, and changes in electricity consumption;
- optimization of the power consumption portfolio (less of coal, more of natural gas, nuclear energy, and renewables);
- expansion and deepening of international collaboration, establishment of a regional energy market, and participation in the global governance of the energy-related issues;
- development of energy-related technologies and innovative energy systems.

China has always considered the development of renewable energy from different angles: control of pollution and emissions, improvement of the public welfare, and, more importantly, reduction of dependence on fossil fuels. In addition, China has simultaneously set the task of localization of all the equipment required for energy generation (Mastepanov 2019), thereby ensuring national security in renewable energy. Fang (2010), Wu and Storey (2007), and Mastepanov (2019), among others, emphasize two dimensions in China's contemporary energy policy (Fig. 5).

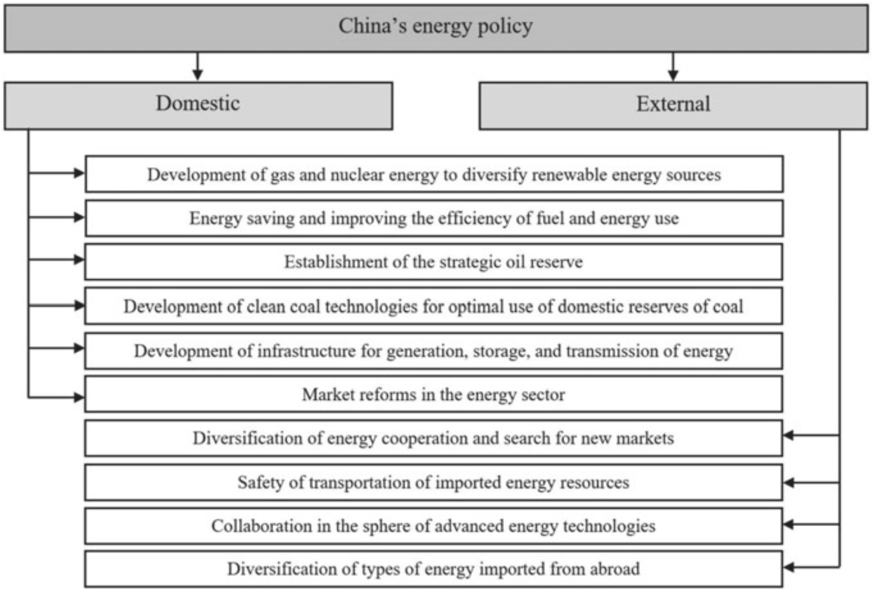

Fig. 5 Two dimensions in China's energy policy. *Source* Authors' development

The domestic dimension is aimed at ensuring the growth of energy efficiency, curbing the demand for energy resources in the country to reduce dependence on imports, and developing the domestic power sector, including attracting foreign investment, technologies, and competencies for the exploration and exploitation of hard-to-reach and unconventional deposits of hydrocarbons. China's government has established the Renewable Energy Development Fund to subsidize wind and solar power plants. The fund covers the difference between the tariffs for renewable energy supply and the provincial benchmark tariff for coal energy. Minimum power factor requirements for wind and solar energy were introduced at the provincial level in 2016 (Zeng et al. 2018). Renewable power is prioritized when drawing up an annual energy generation plan. The central government has been encouraging the expansion of the renewable power sector through price incentives (Energy Research Institute 2015).

The external dimension involves the diversification of sources of imports, monitoring of the hydrocarbon reserves in other countries through the participation of Chinese capital in the exploration of oil and gas fields abroad, as well as strengthening ties with countries that supply hydrocarbons and other types of energy to China. Main tasks include the diversification of cooperation in the power sector and the search for new markets, safety of energy transportation from abroad, international collaboration in the development and implementation of advanced energy-related technologies, and diversification of types of energy purchased from abroad.

According to the State Council Information Office of the People's Republic of China (2020), the country prioritizes further promotion and use of renewable power as a principal element of its transition to carbon neutrality. In the hydropower sector, China intends to focus on major rivers in the southern and western parts of the country, where the government wants to establish substantial hydropower facilities, develop the network of small and medium-sized hydropower installations, and increase investment in river ecology restoration. In the wind energy sector, the government encourages the setup of onshore and offshore windmills, particularly across central and eastern provinces and coastal territories. Solar energy generation will implement a “leader board” incentive to stimulate production on the basis of market competition.

3.3 Russia

For a long time, there have been no state programs to support the renewable power sector in Russia. In 2013, the government adopted the State Program on Energy Efficiency and Development of the Energy Sector (Government of the Russian Federation 2014). It assumed that by 2024, Russia would have installed approximately 2.2 GW of solar energy facilities, 3.4 GW of wind farms, and above 200 MW of small hydropower power plants. The production of power generation equipment must be localized in Russia (70%, 65%, and 65%, respectively) (Table 5).

In June 2021, the national policy provisions in renewable power were updated to capture the 2035 horizon (Government of the Russian Federation 2009). The program now defines the goals and principles of renewables’ use and contains targets for the volume of power generation with the utilization of renewable sources and consumption of energy. It is expected that by 2035, the contribution of the renewable power sector to Russia’s total energy balance will reach 6% (4.5% by 2024). To achieve these targets, Russia plans to incentivize the utilization of renewable power sources using the following eight principles:

- coordination of activities for the implementation of public policy related to developing the power sector, including the utilization of renewables;

Table 5 Target parameters of the introduction of new renewable energy generation capacity in Russia until 2024

Type of energy generation	Introduction of new energy generation capacity, MW								Localization target, %
	2014	2018	2020	2021	2022	2023	2024	Total	
Wind energy	–	400.0	500.0	500.0	500.0	500.0	214.7	3,415.7	65.0
Solar energy	35.2	270.0	270.0	162.6	162.6	240.0	238.6	2,238.0	70.0
Mini hydropower plants	–	–	16.0	24.9	33.0	23.8	41.8	210.0	65.0
Total	35.2	670.0	786.0	687.5	695.6	763.8	495.1	5,863.7	–

Source Authors’ development based on Government of the Russian Federation (2009)

- state support for developing the renewable power sector in accordance with the budget legislation of Russia until renewable energy technologies may compete with fossil fuels in the market;
- state support for developing the renewable power sources in accordance with the budget legislation to achieve the target level of attracting investments;
- incentivizing the production of basic and (or) auxiliary power generating equipment in the sphere of renewable energy;
- state support for export of basic and (or) auxiliary power generating equipment in the sphere of renewable energy;
- ensuring the availability of information about elaborating and implementing public policy measures in the renewable power sector;
- stakeholders' participation in the elaboration and use of public policy measures in the sphere of renewable power.

The above mentioned public policy measures include the improvement of the state governance system in the renewable power sector, development of infrastructure for generation, storage, and transmission of energy derived from all kinds of renewable sources, and creation of fair and just conditions for all producers and other stakeholders in the renewable energy market (Fig. 6).

The improvement of the governance system includes six kinds of measures (Government of the Russian Federation 2009):

- elaboration and revision of target indicators in the renewable power sector;
- monitoring the achievement of established targets, including their periodic clarification based on Russia's priorities in the economic, energy, and environmental spheres;
- better data collection, analysis, and state statistical reporting related to the use of renewable power facilities
- development and regular updating of the allocation scheme of power generation facilities across Russia, taking into account the location of productive forces, economic development of individual territories, and available renewable energy resources, including a list of projects for the construction of new and reconstruction of existing power generation facilities;
- development and implementation of measures to attract non-budget (private, foreign, etc.) investments in the construction of new and reconstruction of existing power generation facilities in the renewable energy sector to achieve target thresholds of capacity growth (including the attraction of venture capital);
- elaboration of a set of measures to promote the growth of small and medium-sized power generating facilities in the renewable energy market.

  Russia mainly focuses on developing the infrastructure for producing and transmitting hydropower, solar, wind, and other kinds of renewable energy. In this sphere, the following measures are implemented (Government of the Russian Federation 2009):

- increase in the efficiency of research and innovations for the development of the renewable energy sector and maintenance of power generating facilities;

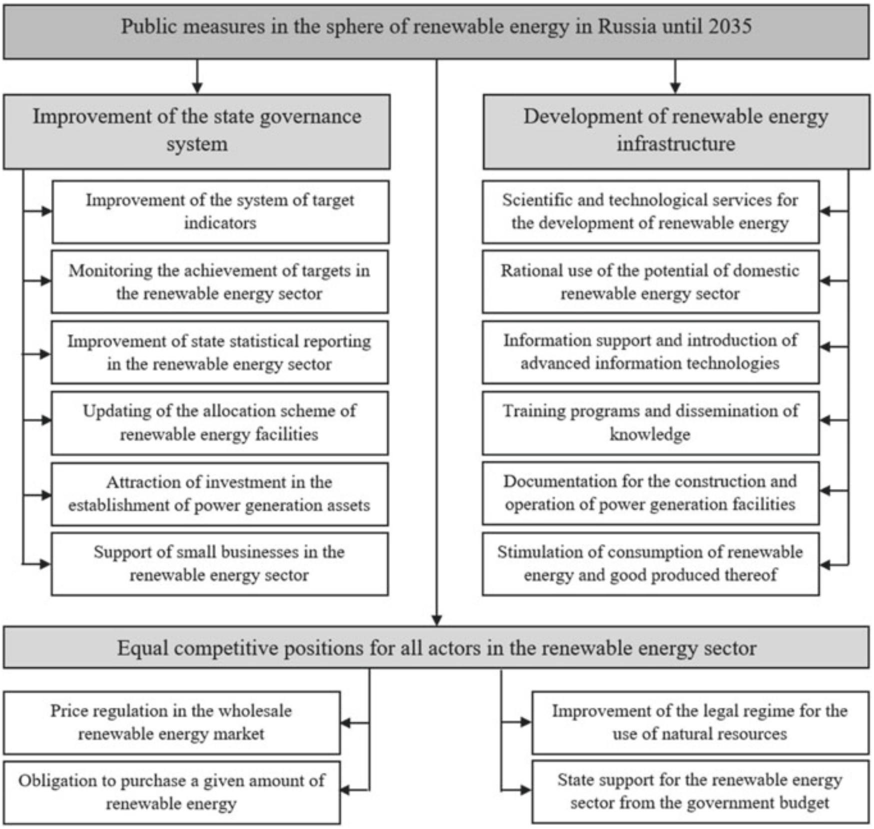

Fig. 6 Measures to develop the renewable energy sector in Russia. *Source* Authors' development based on Government of the Russian Federation (2009)

- rational use of the potential of domestic industry for promoting renewable power solutions, including through providing state support for export of basic and (or) auxiliary power generating equipment;
- establishment of the information environment, including the assistance in the creation and development of an expert and consulting network of engineering and information support for developing the renewable power sector and introducing advanced information technologies of management;
- development and implementation of programs for the dissemination of knowledge about the use of renewable power and the training of specialists in the spheres of design and operation of power generation facilities;
- stimulation of economic entities and households to consistently increase consumption of energy derived from renewable sources and consume related goods and services.

Finally, Russia prioritizes establishing a fair market environment and equal conditions for competition between producers and suppliers of renewable energy (Government of the Russian Federation 2009). Policy measures applied in this sphere include the obligation of energy market actors to purchase a given amount of renewable power, improvement of regulations related to the use of natural resources for constructing and operating power generating facilities, and additional support mechanisms for the renewable power sector laid down by Russia's budget legislation.

4 Gaps and Challenges

Based on the above review of the regulatory framework in renewable energy, we can say that renewable energy is an essential and promising industry for both China and Russia. This vision is appropriately reflected in the legislation of both countries and expressed in the support measures provided to producers and exporters of power generation equipment and renewable energy itself. However, the two countries are obviously facing a number of problems and challenges in this area. Some of these issues are attributes of the early growth of renewable energy as a new industry. Thereby, they are more or less common to the entire global community—the state of technology, renewable energy efficiency, avoidance of short-term failures or load peaks, long-term stability of power generation, competitiveness of renewable sources compared to conventional energy, and many others. The individual characteristics of the renewable power sector in China and Russia should be viewed through these lenses.

The volume of technically available renewables in Russia is equivalent to 4.6 billion tons of standard fuel. However, given the current situation in the global energy market and the state of technology in Russia's renewable energy sector, the exploitation of these resources without support from the state is of marginal economic benefit to producers (except for hydropower). As noted above, the total installed capacity of renewable energy facilities (excluding hydropower plants above 25 MW) is below 2,200 MW. The contribution of renewable sources to Russia's energy balance is only 1%. The following three reasons could explain such backwardness of the renewable power sector in Russia:

- competitive weakness of renewable power projects compared to fossil fuels (Russia's abundance with fossil fuels, orientation on oil, gas, and coal, and volatile oil and gas prices in the world markets, but still comfortable overall level of profit for the state-backed oil and gas tycoons);
- institutional barriers related to the lack of comprehensive and well-detailed regulatory acts and policies that would incentivize the spread of renewable power solutions in the economy;
- poor infrastructure in the renewable power sector, including (1) insufficient level and quality of research and analysis related to renewables, (2) inadequate information environment, including information on potential power resources and data

on the parameters of ongoing projects and individual power plants, (3) weak regulatory framework and software tools in the spheres of engineering and operation of renewable power facilities, (4) lack of training in the sphere of renewable technologies and low awareness of renewable power in the society.

Russia's grid system (power and electricity transmission, heating, and fuel delivery) is highly centralized and focused on conventional energy (Remizova 2017). Hydropower is an integral part of the grid system, but integrating other types of renewable energy into the national-level system of energy production and distribution is poor. There required the construction of power lines, heat pipelines, energy storage facilities, and other infrastructure facilities.

China is also facing a number of challenges in renewable energy, despite the radical growth of this sector in recent years. As in Russia, a significant amount of renewable energy generated in China is lost due to the still weak integration of renewable energy facilities in the single energy grid (Khazova 2019). The skyrocketing growth of renewable energy since the 2000s has been more than impressive, but it has resulted in the problem of adequate inclusion of new power generation capacities into a single power supply network—both due to the quality of the energy produced and the absence or shortage of power transmission networks in remote locations where renewable is generated. Xu et al. (2021) emphasize disproportions in allocating renewable energy capacities across China. For example, in western China, solar energy generation does not match consumption. The wind energy capacity is concentrated in the northern and eastern coastal provinces. Therefore, renewable energy cannot compete with coal power.

Another challenge is the low operational efficiency of power generation, which affects the ability to cover the demand for energy with renewable energy resources alone. There is still a problem of insufficient development of technologies and innovations. Until recently, China had imported many of the power generation solutions and key technologies. China has been actively closing this gap by promoting domestic research and development in renewable energy, but some producers still lack innovations and domestic development centers.

Despite the strategic orientation on carbon neutrality in the future, the government's support for renewable energy policies is still insufficient (Xu et al. 2021). Governance, strategies, programs, and policies in public administration are divided between different departments. It is critical to eliminate gaps in regulations in renewable energy. At the strategic level, government agencies should develop a long-term-oriented renewable energy vision that would take into account regional diversities and territorial disparities in the allocation of renewable energy facilities. Technically, the government should support technology improvement and internal innovation. For the integrated development of the system, all stakeholders should be supported, including producers, consumers, research institutes, and local authorities.

5 Prospects for China-Russia Collaboration

5.1 Future-Oriented Outlook

Despite the problems, gaps, and challenges outlined above, cooperation between China and Russia in renewable energy has become increasingly productive in recent years. The parties have concluded several cooperation agreements and developed and implemented investment projects. Thus, Solar Systems LLC (a representative of Chinese company Amur Sirius in Russia) has established solar energy parks in several regions in Central and Southern Russia (Samara, Astrakhan, Volgograd, Stavropol, and Kalmykia). Due to the establishment of eleven solar energy sites, Russia's total installed solar energy capacity has increased by 255 MW. The expected Solar Systems' demand for photovoltaic modules for implementing and maintaining these investment projects exceeds 830,000 units. To meet this demand, Solar Systems cooperates with Shunfeng International Clean Energy Limited (SFCE), one of the world's largest suppliers of integrated eco–friendly energy-saving solutions. A memorandum of understanding signed between these companies provides the possibility of developing a partnership to process materials, supply solar modules, and other joint activities in the sphere of solar energy. China is the largest manufacturer of solar panels in the world. In this context, the development of solar energy in Russia allows both countries to work together on emerging energy issues and related renewable technologies within the framework of the existing strategic partnership between the countries. Solar energy could provide additional incentives to the electronics industry, high-precision processing of materials, and research and development of new chemical compounds and substances.

RUSNANO, Russia's high-tech company, is partnering with Chinese counterparts in the wind energy sector. In 2016, it established the Russia-China Joint Investment Fund in collaboration with Zhongrong Trust International Co., LTD. (Zhongrong). Zhongrong is one of the largest financial institutions in the Asia Pacific, specializing in direct investments and having practical experience in financing large-scale innovative projects across the globe. The $500 million capital serves investment projects in Russia (70%), China, and other countries. Since in both Russia and China, a significant part of the energy generated by wind and solar power plants is not supplied to the national-level power grids, collaboration should provide for a whole range of measures to change the situation. Among them are the advanced development of smart power grids, increase in the adaptability and efficiency of local and regional power systems, optimization of allocation of power generation facilities, and encouragement of consumption of renewable energy at the local level (for instance, wind farms in the coastal regions in Eastern China, Russia's Far East, and Russia's High North).

Such achievements in the sphere of Russia-China cooperation in renewable energy, along with the recently released 14th five-year plan in China, give reason to expect China to fulfill its obligations to reduce greenhouse gas emissions. In 2021, China's government aimed at reducing energy intensity by 3%. By 2025, the government seeks to further reduce energy intensity by 13.5% and carbon intensity by 18%, while by 2060, China is going to achieve carbon neutrality (Cooper 2021; Stern and Xie 2020). The use of solar energy reduces carbon dioxide emissions by about 370 million tons, sulfur dioxide emissions by 1.2 million tons, nitrogen oxide emissions by 900 thousand tons, and soot emissions by about 1.1 million tons. Wind energy development provides annual savings of about 150 million tons of coal, resulting in a reduction in carbon dioxide emissions by approximately 380 million tons, sulfur dioxide by 1.3 million tons, and nitrogen oxide by 1.1 million tons (Mastepanov 2019). In the context of China's attempt to decarbonize the economy, collaboration initiatives that cut emissions as well as stimulate economic growth are particularly promising (Hepburn et al. 2020). China's fulfillment of its obligations to reduce greenhouse gas emissions, combined with the desire to diversify energy imports, may undermine the prospects of Russia-China energy cooperation (export of fossil fuels from Russia and import of technological equipment for the energy sector from China). To mitigate this threat, both countries should establish tighter interregional ties and develop cross-border collaboration in the sphere of renewable energy. This would create a more robust basis for cooperation at the grassroots level between small and medium-sized enterprises, not only between large energy corporations.

5.2 Cross-Border Collaboration in the Far East and Russia's North

Russia's Far East is one of the territories where cross-border cooperation between China and Russia is already intensive now and even more promising in the future (in view of a potential expansion of joint projects northward to Russia's High North and territories along the Northern Sea Route). In the Russian Arctic, China already participates in collaborative energy projects with Russia (Yamal LNG and Arctic LNG). Many scholars (Gao et al. 2021; Dun and Lukin 2018; Wang 2020; Huang and Korolev 2015) agree that since China is primarily interested in creating additional energy generation for domestic needs, this intention makes the Far East and Russia's North particularly attractive to Chinese investors.

The estimated renewable energy capacity in the Far East is 500 MW. RusHydro, one of Russia's largest power generating companies, is partnering with Power China in the Far East. The two companies have launched wind complexes in the Kamchatka Peninsula and the Sakhalin Island. In total, RusHydro plans to build 139 solar energy stations and 35 wind farms. RAO Energy Systems of the East (part of RusHydro Group) signed an agreement with Dongfang Electric International Corporation on cooperation in the energy sector in the Far East. The Ministry of Energy of Russia and the State Electric Grid Corporation of China are working on developing wind energy generation in the north of the Far East. The wind farm project provides for the transmission of electricity to China. China itself implements province-level projects for the processing of agricultural waste into biogas. A particular focus is made on the northeastern provinces bordering Russia's Far East (Primorye, Khabarovsk, Amur, and other territories). There will be established demonstration sites for testing power generation technologies based on the energy of sea waves and tides (total installed capacity of over 50 MW).

Both the Far East and the Russian Arctic are extremely sparsely populated, which means distances between power generation sites and power consumption centers (settlements, industrial facilities, etc.) could be rather long. In addition, climatic conditions make energy production from renewable sources either more expensive or completely inviable (for example, extremely low temperatures and polar nights in the High North). On the other hand, a low integration of renewable sources into a single grid system discussed above can also open up prospects for Russia-China cooperation in remote territories in the Far East and the Arctic. In these territories, renewable energy development is possible within the distributed power systems, in which minor losses in networks during energy storage or transmission are permissible. According to Remizova (2017), when the power supply is decentralized, the competitiveness of all types of renewable energy against conventional fossil fuels increases.

5.3 Mechanisms

Interregional cooperation in the sphere of renewable energy requires establishing a set of tools for regulation and promotion of the Russia-China business and investment ties. Climate bonds are particularly effective at the intergovernmental level in incentivizing joint projects (Avramenko and Vorfolomeev 2017). In 2016, the New Development Bank established by BRICS countries issued green bonds in the amount of 3 billion yuan ($448 million) in China's bonds market with reduced exchange risks to domestic investors. The funds have been used to implement environmental projects in the BRICS countries, including in the field of renewable energy (Avramenko and Baiguskarova 2018). The Bank also declared the intention of increasing the issuance of bonds in local currency in China and Russia (New Development Bank 2016; BRICS Policy Center 2018).

At the national level, Russia adopted the procedure to support renewable energy in retail markets and geographically isolated districts (Arctic territories and the Far East) (Government of the Russian Federation 2015). The document outlines the introduction of long-term tariff regulation of renewable power in retail markets. Regional authorities establish the procedure and requirements for conducting competitive selections of investment projects and their further inclusion in the energy sector in particular territories. Therefore, the adopted regulations allow administrative entities in the Far East and other regions of Russia to make decisions on supporting joint projects with China in the renewable energy sector. In 2020, Russia's government approved the following mechanisms to stimulate the generation of renewable power (Government of the Russian Federation 2020):

- competitive selection of investment projects for establishing the renewable power facilities to include such projects in the regional development programs, including detailed regulation of tenders;
- tender-based price ceilings (tariffs) for energy produced from renewable sources instead of regulating prices;
- clarification of the rules and procedures for the qualification of power generating facilities;
- development of the procedure for concluding contracts for the purchase and sale of electric energy with grid organizations, clarification of terms of such contracts, and simplification of the procedure for determining the volume of sales of electric energy under such contracts;
- improvement of the rules for maintaining the register of issuance and repayment of certificates confirming the volume of energy generation from renewable sources.

New rules and principles of investment projects in renewable energy have been defined, which must be taken into account when concluding Russia-China investment agreements. The most significant change is that investment projects are now selected based on the principle of the integrated performance of renewable energy projects, not the costs minimization principle. The government sets the maximum possible support volume and goes down from this bar when making a selection decision. The government set clear criteria for determining the capacity of renewable energy facilities supplied to the market and payable by consumers. At the same time, the support measures are conditioned by the need for investors to comply with the requirements in the field of localization of energy equipment components (forcing Chinese manufacturers to localize part of production and technology in Russia) and the requirements for mandatory export volumes (stimulating the entry of Russian companies into the Chinese energy market or the entry of joint Russia-China enterprises into the global market).

It is expected that the implementation of the proposed measures will increase the investment attractiveness of Russia's renewable energy sector for Chinese investors, as well as stimulate the supply of renewable energy in retail markets. Russia's government intends to extend the program beyond 2024 to improve the potential and support the performance of the renewable energy sector and integrate it into the global production and supply chains (including through cooperation with foreign partners). According to preliminary calculations, the program's implementation will allow the introduction of renewable energy generation with a total installed capacity of more than 6.7 GW in 2023–2035 (Government of the Russian Federation 2020). Such a long-term vision of the renewable energy prospects creates a solid foundation for cooperation with China.

6 Conclusion

Even though fossil fuels continue dominating the energy mix in China and Russia, both countries are making attempts to decarbonize their economies. Compared to Russia, China has made far more significant strides in its ability to transform the energy sector towards green growth. The reforms in the energy sector have resulted in a significant improvement of air quality and reduction of the emissions of sulfur dioxide, nitrogen oxides, and soot. China's transition to low-carbon energy by means of the development of renewable energy seems to be an essential contribution to the mitigation of climate change and the solution of energy challenges the world is facing today. China's energy strategy states that the country will continue providing "forceful support for sound and sustained economic and social development", and making "a significant contribution to ensuring world energy security, addressing global climate change, and boosting global economic growth" (State Council Information Office of the People's Republic of China 2020). In view of both the longer-term effects of climate change and the shorter-term volatilities in the global energy market, renewable energy development is becoming an increasingly attractive option to bridge the gap between economic goals, environmental considerations, and sustainable development. However, in such resource-abundant countries as Russia, renewable energy can hardly compete with cheap and readily available fossil fuels. In this case, the government should step in and support start-ups in various sectors of the renewable energy market, including joint ventures with foreign partners. For China and Russia, such a collaboration could be particularly fruitful due to China's experience and advancement in the area and Russia's natural potential for developing hydropower, solar, wind, and other types of renewable energy. The countries should develop interregional ties between Russia's Far East and High North and China's Northeast to establish a strong foundation for cross-border cooperation between local businesses, not only between the national-level energy tycoons.

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Sustainability Evaluation of Power Systems Using MCDM Techniques

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Abstract Electricity plays a key role in the economic development of any region and in people's quality of life. Its global demand is steadily growing, a trend that is expected to continue in the future. Power plants are usually assessed from technical and economic feasibility points of view. Nevertheless, both the resources of the planet and its capacity to withstand human-induced impacts are limited. Therefore, it is necessary to consider environmental and social criteria at the time of assessing the most important types of power plants. This is the only way to achieve a sustainable electricity sector. Consequently, in this chapter six different multi-criteria decision making methods (MCDM) are described and applied to assess the sustainability of renewable and non-renewable power systems throughout their life cycles, from cradle to grave. In particular, three criteria were considered: levelised cost of electricity (economic), direct job creation (social) and climate change potential including biogenic carbon (environmental). The results of all methods are presented and discussed in depth, adopting different approaches.

Keywords Sustainable development · Sustainability criteria · Renewables · Non-renewable power plants · Multiple attribute decision making

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1 Introduction and Objectives

Electricity is one of the main driving forces for the development of any society, acting as an essential vehicle to facilitate economic growth (Nagarkatti and Kolar 2021). It also plays an important role in people's quality of life. Nevertheless, today, many people, especially in developing countries in Africa, Asia or South America do not have access to electricity (López-González et al. 2019) or, if they do, the electrical network appears to be insufficient, intermittent and highly polluting. To this should be added that world population is steadily growing, which also translates into an increase in electricity demand (Dombi et al. 2014; Mohamed et al. 2020), while the resources of the planet as well as its capacity to withstand the impacts arising from human action are diminishing. A trend that is likely to continue in the years to come.

On the other hand, at the time of extending and improving the electrical network by constructing new power plants, economic and technical feasibility studies are usually performed (Shaaban and Scheffran 2017). However, this approach has proven to be insufficient, if the aim is to pursue a sustainable electricity sector. According to the Brundtland report, development is considered sustainable when current needs are met without compromising the ability of future generations to do the same (Brundtland et al. 1987). In other words, sustainability and sustainable development, in addition to economic and technical issues, include social and environmental aspects. In this regard, there is a widespread belief that renewables are more sustainable than their non-renewable counterparts, since they improve energy security, provide employment opportunities and generate less negative impacts on the environment, among other benefits (Shaaban and Scheffran 2017; Shaaban et al. 2018). Despite this, all power systems present both positive and negative impacts on the economy, society and the environment. As stated by Hacatoglu et al. (2015), it is not possible to claim that a power plant is sustainable until a detailed analysis of economic, social and environmental criteria has been carried out.

Consequently, for some time now, the scientific community has been making efforts to assess the sustainability of different types of power plants all over the world. Diverse approaches were adopted for such a purpose (emergy, life cycle analysis, exergy or multi-criteria, among others) (Wu et al. 2018), being the use of multi-criteria decision making (MCDM) methods the most common one in the specialised literature. By way of example, Begić and Afgan (2007) developed a tool based on the Analysis and Synthesis of Index at Information Deficiency (ASPID) method for assessing the sustainability of different types of power plants in Bosnia and Herzegovina. They considered both renewable and non-renewable alternatives. By contrast, Dombi et al. (2014) focused on the study of renewables. The authors analysed seven indicators throughout a Choice Experiment (CE) survey. The environmental pillar of sustainability was addressed by Hacatoglu et al. (2015) at the time of comparing a wind battery system and a gas power plant for a small community in Canada.

More recently, Shaaban et al. (2018) combined the Analytic Hierarchy Process (AHP) together with the Simple Additive Weighting (SAW) technique to compare the sustainability contribution of three renewable and four non-renewable types of power plants in Egypt. Also adopting an hybrid approach, Wu et al. (2018) assessed the sustainability of eight coal power units in China. To this end, they employed the Areal Grey Relational Analysis (AGRA) method in combination with AHP and the entropy weight technique. López-Gónzalez et al. (2019) studied six micro-hydroelectric power plants in Venezuela. The authors analysed economic, social, technical, institutional and environmental criteria by using historical databases. A single type of power plant was also assessed by Mohamed et al. (2020). In this case, the authors focused on biomass gasification with and without carbon capture and storage technology. Despite the fact that they considered several indicators, an integrated approach for the numerical results was not adopted. Spider graphs were used instead. The effect that carbon capture technologies can cause on sustainability was also addressed by Nagarkatti and Kolar (2021). This time, the authors assessed different advanced coal technologies for India by combining AHP with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Indicators belonging to the main pillars of sustainability were taking into account. In contrast, renewables were analysed by Sedghiyan et al. (2021) for Iran. The authors employed different MCDM methodologies, in particular, AHP, AHP combined with SAW, and AHP in conjunction with TOPSIS. Economic, social, technical, environmental and energy security indicators were considered.

There are many other studies assessing the sustainability of different types of power plants under diverse approaches. Nevertheless, from the existing literature, it is clear that there is no consensus on what is the adequate way of performing this type of studies (Hacatoglu et al. 2015). In fact, there are important differences in terms of the MCDM technique to be used, the criteria analysed and the technologies considered. Consequently, the main objective (and motivation) of this study is to shed some light on this relevant topic for energy planning. Therefore, some of the most common MCDM techniques will be used for solving the same case study, which consists on assessing the sustainability of some renewable and non-renewable energy sources through the use of a limited number of relevant indicators at economic, social and environmental levels. The reminder of this chapter is structured as follows. A brief description of MCDM techniques is presented in Sect. 2. The methods employed in this study are also theoretically described in the same section. Information on the case study (criteria, power plants, boundaries, limitations, among other information) is provided in Sect. 3. The results are included and discussed in Sect. 4. Finally, Sect. 5 contains the main conclusions drawn from the study as well as potential future developments.

2 Materials and Methods: Multi-criteria Decision Making (MCDM) Techniques

Multi-criteria decision making (MCDM) methods can be defined as a set of tools used to select among different alternatives according to their performance against multiple criteria or indicators. These criteria or indicators are often in conflict (De Brito and Evers 2016; Tzeng and Huang 2011), that is, the improvement of one of them usually leads to a worsening in the performance of other criteria. In other words, the necessity of applying these techniques lies in the fact that there is usually no alternative with the best results for all indicators.

MCDM methods were classified by Hwang and Yoon (1981) into two categories: (i) multiple attribute decision making (MADM), and (ii) multiple objective decision making (MODM) (Fig. 1). The first one deals with decision problems in which there is a discrete number of explicitly known alternatives to be assessed (discrete problems), while MODM is particularly oriented to design and planning problems with no predetermined alternatives (continuous problems), in which the decision maker looks for a set of optimal solutions (equally good under certain constraints) (Penadés-Plà et al. 2016; Tzeng and Huang 2011). MODM methods are out of the scope of this chapter.

There are different ways of classifying MADM techniques. Nevertheless, the proposal by Penadés-Plà et al. (2016) is one of the most common classifications (Fig. 1). It is based on the taxonomies proposed by Hajkowicz and Collins (2007) and by De Brito and Evers (2016).

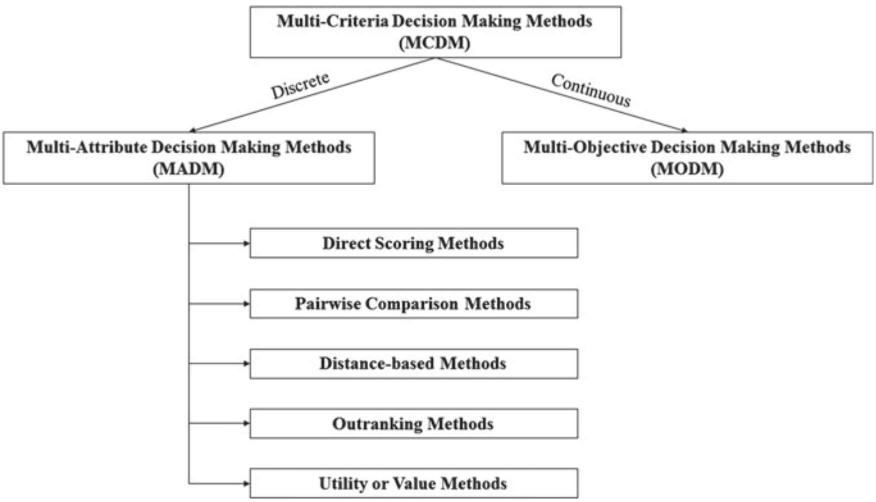

Fig. 1 Classification of multi-criteria and multi-attribute decision making methods (MCDM and MADM, respectively). *Source* Own based on Hwang and Yoon (1981) and Penadés-Plà et al. (2016)

Direct scoring methods are the simplest MADM techniques. Each alternative is assessed against each criterion or indicator by using basic arithmetic operations. They are mainly based on the construction of a decision matrix (with the values that each indicator takes for each alternative) that is usually normalised. The Simple Additive Weighting (SAW) method (Churchman and Ackoff 1954; Klee 1971), also known as weighted sum approach, or the Complex Proportional Assessment (COPRAS) (Zavadskas et al. 1994, 2004) technique are two examples that belong to this group.

Pairwise comparison methods involve comparing the relative importance of all the pairs of criteria or indicators by using any type of scale. Therefore, they are usually employed for defining the weights of the criteria that take part in the decision making process. Nevertheless, they can also be used to compare how each alternative performs in contrast with the others (pairwise comparisons) for each specific criterion. The Analytic Hierarchy Process (AHP) (Saaty 1980, 1990), the Analytic Network Process (ANP) (Meade and Presley 2002; Saaty and Vargas, 2006) or the Measuring Attractiveness by a Categorical Based Evaluation TecHnique (MACBETH) (Bana e Costa et al. 2011; Bana e Costa and Vansnick 1994) fall into this category.

Distance-based methods. This family of techniques, as its name suggests, assesses the distance between each real alternative and a specific theoretical solution. This solution can be the one with the optimal result for all the indicators considered in the assessment, or even the opposite, that is, the potential worst alternative, among other options. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon 1981; Opricovic and Tzeng 2004) or the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic 1998; Opricovic and Tzeng 2007) are two of the most frequently used distance-based methods, although there are other techniques such as compromise and goal programming (Romero et al. 1998).

Outranking methods are based on the establishment of preference or dominance relationships among one alternative and the others for certain criterion. In contrast with distance-based methods, outranking approaches do not need to consider an optimal solution. Some of the most common outranking techniques include Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Brans and Mareschal 1986; Brans and Vincke 1985), ÉLimination et Choix Traduisant la REalité (ELECTRE) (Govindan and Jepsen 2016; Roy 1968), or Organization, Rangement Et Synthese De Donnes Relationnelles (ORESTE) (Pastijn and Leysen 1989; Roubens 1982).

The basis of **utility or value methods** lies in the use of mathematical expressions (utility or value functions) that assess the level of satisfaction of each criterion or indicator. In other words, those functions transform the value (measured in the corresponding real units) that each alternative adopts for each criterion into a dimensionless parameter that indicates how good the performance of the alternative is. Utility or value methods usually adopts a compensatory approach, that is, a bad result for certain indicator can be compensated by a good one for other criterion. Multi-Attribute Utility Theory (MAUT) (Han 2004; Sarin 2013), Multi-Attribute

Value Theory (MAVT) (Fishburn 1967; Keeney and Raiffa 1993) or Modelo Integrado de Valor para una Evaluación Sostenible (MIVES) (de la Cruz et al. 2014; Gómez et al. 2012) are some of the techniques belonging to this group.

In this chapter, at least one method belonging to the five MADM sub-groups will be used for assessing the sustainability of renewable and non-renewable power plants. In particular, SAW, AHP, TOPSIS, VIKOR, PROMETHEE and MIVES will be applied to the same case study. By doing so, it will be possible to compare the results provided by each method, identifying potential advantages and disadvantages for all of them. In the following sub-sections, a brief description of these six methods is provided. The reader should bear in mind that there is no exact correspondence among the nomenclatures employed for the different techniques.

2.1 Direct Scoring Method: SAW

The SAW method was first proposed by Churchman and Ackoff (1954) and it is probably the most widely used MADM technique (Tzeng and Huang 2011). The main reason for that is its simplicity, since it is based on the use of Eq. (1):

$$A_i = \sum_{j=1}^{m} w_j \cdot u_{ij} \tag{1}$$

where $A_i$is the score or performance of alternative i (with $i = 1, 2, 3, \ldots, n$ (number of alternatives under assessment)). It varies between 0 and 1, the worst and best solutions, respectively; and it is a dimensionless parameter. In Eq. (1), sub-index j is used for identifying each one of the m criteria or indicators; w_j is the weight or relative importance of criterion j (the sum of all weights must be equal to 1), and u_{ij} is the normalised value of alternative i for the jth criterion or indicator. As with A_i, u_{ij} also falls within the interval [0, 1]. If the objective of criterion j is to maximise its value (larger value implies a better performance), u_{ij} is calculated through Eq. (2):

$$u_{ij} = \frac{x_{ij}}{x_{jmax}} \tag{2}$$

In Eq. (2), x_{ij} is the input value that alternative i adopts for criterion j, measured in the corresponding real units; while x_{jmax} is the maximum value adopted by one of the alternatives i for the jth criterion or indicator, measured in the same units. On the other hand, there can be criteria in which a higher value is associated with a poorer performance, for example, a cost. In such a cases, Eq. (3) is used for obtaining u_{ij}:

$$u_{ij} = \frac{x_{jmin}}{x_{ij}} \tag{3}$$

where x_{jmin} is the minimum value adopted by one of the alternatives i for indicator j. The reader can find in Tzeng and Huang (2011) a different option for estimating u_{ij}.

2.2 Pairwise Comparison Method: AHP

AHP was developed by Saaty (1980) for selecting alternatives according to multiple criteria or indicators that are usually organised in a hierarchical way. It can also be used to determine the weights of the criteria that take part in a MADM problem. In other words, AHP can be used directly to solve MADM problems, or as a support technique for defining the weights when another MADM methodology is used for the final selection of alternatives. The reader can find in Fig. 2 the hierarchical scheme constructed for applying AHP to the case study described in Sect. 3. If the problem were more complex, two or more hierarchy levels could have been defined for the criteria.

This method is based on the relative ease with which humans can make pairwise comparisons, as opposed to the problems (inconsistencies) that arise when a large number of attributes are compared in a general way.

In other words, after defining the hierarchical structure, a set of pairwise comparison matrices (or decision matrices) are constructed. One matrix (or more, depending on the hierarchical scheme) aims to obtain the weights (w_j) for the criteria (or sub-criteria) (Fig. 3).

In Fig. 3, a_{ij} indicates how important is criterion i in comparison with criterion j, being m the total number of criteria. Of course, if criterion i is k times more important than criterion j (a_{ij} adopts a value of k), criterion j is k times less relevant than criterion i (a_{ji} takes a value of k^{-1}). Furthermore, the elements of the main diagonal are equal to 1. For defining each a_{ij}, the Saaty scale is usually used (Saaty 1980). This scale translates semantic labels such as slightly more important, or much more important, among others, into numerical values.

Apart from the decision matrix A for the weights, similar matrices will also be constructed for each one of the criteria. The terms a_{ij} now reflects how is the performance of alternative i in comparison with alternative j for a specific indicator or

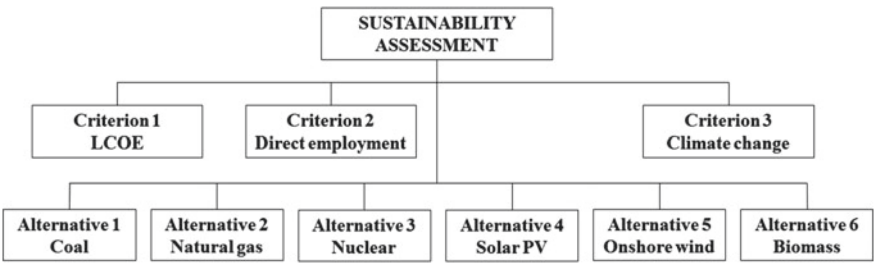

Fig. 2 AHP hierarchical scheme for the case study described in Sect. 3

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1m} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{im} \\ \vdots & & \vdots & & \vdots \\ a_{m1} & \cdots & a_{mj} & \cdots & a_{mm} \end{bmatrix}$$

Fig. 3 Example of pairwise comparison matrix for weights

criterion. If the indicator is qualitative the Saaty scale can be used to transform subjective opinions into numbers. Nevertheless, if the indicator is quantitative and the values that the different alternatives adopt are known, it is also possible to create the corresponding decision matrix. In such case, if the objective of the indicator is to maximise its value, a_{ij} will be the real value that alternative i takes (for example x_i) divided by the value for alternative j (x_j). On the other hand, if a larger x value implies a poorer performance, a_{ij} is calculated by dividing x_j by x_i.

Once all the decision matrices are defined, the next step of AHP consists of calculating the eigenvector associated with the maximum eigenvalue for each one of the matrices. The components of the eigenvector associated with matrix A in Fig. 3 are the weights for the criteria. Consequently, their sum is equal to 1. On the other hand, the components of the eigenvector linked to a matrix that compares all the alternatives against a certain criterion are the performances or scores. The sum of all the scores is also equal to 1, and the higher is the score, the better is the performance. The reader can find in de la Cruz et al. (2014) or in Tzeng and Huang (2011) more information on eigenvector estimation.

The reader should bear in mind that decision matrices are not strictly needed for quantitative indicators, since the same results will be obtained by performing a normalisation process (equivalent to the one described in Sect. 2.1 for SAW, but, this time, being the sum of the normalised values for each indicator equal to 1). Finally, AHP allows the decision maker to obtain one single score for each alternative, by adopting a weighted sum approach, similar to the one of Eq. (1).

2.3 Distance-Based Method: TOPSIS

TOPSIS was proposed by Hwang and Yoon (1981) under the assumption that the best alternative should be the closest one (shortest distance) to the ideal solution and, at the same time, should have the farthest distance from the negative ideal solution (Opricovic and Tzeng 2004).

As with other MADM methods, TOPSIS starts from a decision matrix with the values x_{ij} that alternative i (A_i) takes for criterion or indicator j (C_j) (Table 1). This

Table 1 Example of decision matrix including the weights for TOPSIS

Decision matrix				
Alternatives/criteria	C_1	C_2	...	C_m
A_1	x_{11}	x_{12}	...	x_{1m}
A_2	x_{21}	x_{22}	...	x_{2m}
⋮	⋮	⋮	⋮	⋮
A_n	x_{n1}	x_{n2}	...	x_{nm}
w_j	w_1	w_2	...	w_m

matrix could also include, in its last row, the weights w_j. The sum of the weights must be equal to 1.

The next step consists of transforming the decision matrix into a normalised one, with the dimensionless values r_{ij} that alternative i (A_i) adopts for criterion j (C_j). Equation (4), for $j = 1, \ldots$, n, is used for such a purpose (Opricovic and Tzeng 2004):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}\left(x_{ij}^2\right)}} \tag{4}$$

After that, the weighted normalised decision matrix is constructed, by taking into account the weight (w_j) of each one of the criteria or indicators:

$$v_{ij} = w_j \cdot r_{ij} \tag{5}$$

At this point it is possible to define the ideal and the negative ideal solutions. The ideal solution adopts, for each criterion j, the best v_{ij} value (v_j^+). This value, v_j^+, is the highest v_{ij} if the jth criterion must be maximised (larger value implies better performance). Nevertheless, if the aim is to minimise criterion j, v_j^+ is the minimum v_{ij}. On the other hand, the negative ideal alternative takes, for each jth criterion, the worst v_{ij} value (v_j^-). Then, the Euclidean distances to the ideal and negative ideal solutions, D_i^+ and D_i^- respectively, are calculated for each alternative i (Eqs. (6–7).

$$D_i^+ = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^+\right)^2} \tag{6}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^-\right)^2} \tag{7}$$

The final performance score (S_i) for alternative i (A_i) is estimated through Eq. (8).

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (8)$$

S_i varies between 0 and 1, the worst and best possible values, respectively.

2.4 Distance-Based Method: VIKOR

This method was developed by Opricovic (1998) and, as TOPSIS, it starts from a decision matrix with values x_{ij} (Table 1), being i the sub-index for alternatives, and j the one for criteria or indicators. The first step implies selecting the best and worst x_{ij} values for each criterion. If the objective is to maximise criterion j, the best ($x_j{}^+$) and worst ($x_j{}^-$) values are estimated by using Eqs. (9) and (10), respectively. The opposite is true for those cases in which the criterion must be minimised.

$$x_j^+ = max_i(x_{ij}) \quad (9)$$

$$x_j^- = min_i(x_{ij}) \quad (10)$$

The next step entails calculating a new matrix, in which each x_{ij} of the decision matrix is transformed through Eq. (11):

$$s_{ij} = w_j \cdot \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-} \quad (11)$$

From the result of Eq. (11), it is possible to estimate parameter S_i for each alternative i (Eq. 12), being m the number of criteria. S_i is usually known as the utility measure (Zheng and Wang 2020).

$$S_i = \sum_{j=1}^{m} s_{ij} \quad (12)$$

Once S_i is calculated, R_i (regret measure, (Zheng and Wang 2020)) is computed following Eq. (13) for each ith alternative:

$$R_i = max_j(s_{ij}) \quad (13)$$

The maximum and minimum values for S_i and R_i are denoted as S^+, R^+, S^- and R^-, respectively. Consequently, for each alternative i, it is now possible to calculate Q_i (benefit ratio, (Zheng and Wang 2020)) (Eq. (14)).

$$Q_i = v \cdot \left(\frac{S_i - S^-}{S^+ - S^-} \right) + (1 - v) \cdot \left(\frac{R_i - R^-}{R^+ - R^-} \right) \tag{14}$$

In Eq. (13) v is the weight of the strategy "the majority of criteria" as pointed out by Opricovic and Tzeng (2004) and by Tzeng and Huang (2011). Its value falls within the interval [0, 1] and it serves to ponder the two distances considered in Eq. (14), one distance associated with S and the other with R (Sánchez-Garrido et al. 2021). In this chapter, a value of 0.5 will be used for v.

Alternatives can be ranked according to S_i, R_i and Q_i parameters, from the smallest to the largest value. In other words, the smaller the value of S_i, R_i or Q_i, the better the alternative is in the corresponding rank. Finally, VIKOR allows the user to propose a compromise solution: the one with the lowest Q value. Two conditions should be fulfilled for such a purpose. The first one is usually known as the "acceptable advantage" condition and it is shown in Eq. (15):

$$Q'' - Q' \geq \frac{1}{n - 1} \tag{15}$$

where n is the number of alternatives, *Q"* is the benefit ratio of the second alternative in the Q ranking and *Q'* is the benefit ratio of the first alternative in the classification (the lowest Q value).

The second condition is known as "acceptable stability in decision making". In this case, the first alternative in the ranking according to Q must present better results than the second one for S or/and R parameters. If both conditions are fulfilled, the alternative with the lowest Q value is the compromise solution. On the other hand, it is important to note what happens if one of the conditions is not met. If the second condition is not satisfied, the compromise solution is, in fact, a set of solutions consisting of the first two alternatives according to Q. Nevertheless, if the first condition is not achieved, the compromise solution will consist of the first k alternatives of the Q-ranking, being k the highest position that meets Eq. (16).

$$Q^k - Q' < \frac{1}{n - 1} \tag{16}$$

The reader should bear in mind that in Eq. (16), k is not an exponent. It indicates the kth position of Q in the corresponding classification.

2.5 Outranking Method: PROMETHEE

PROMETHEE method is in fact a family of MADM techniques, from PROMETHEE I to PROMETHEE IV. Only the first two PROMETHEE methods will be considered in this chapter. Brans and Vincke (1985) and Brans et al. (1986) were responsible

Table 2 Example of deviation matrix including the weights for PROMETHEE

Deviation matrix for *j*th criterion				
Alternatives	A_1	A_2	...	A_n
A_1	d_{11}	d_{12}	...	d_{1n}
A_2	d_{21}	d_{22}	...	d_{2n}
⋮	⋮	⋮	⋮	⋮
A_n	d_{n1}	d_{n2}	...	d_{nn}

for the birth of this family of methods. As well as TOPSIS and VIKOR, the implementation of PROMETHEE can start from a decision matrix (Table 1) with the real values x_{ij} that each *i*th alternative adopts for each *j*th criterion or indicator. The next step is to create a set of deviation matrices, one matrix for each *j*th criterion (Table 2).

In Table 2, each d_{ab} for criterion *j* is calculated by using Eq. (17) (Behzadian et al. 2010), in which *a* and *b* are sub-indices linked to the different *n* alternatives under assessment and *j* is not an exponent.

$$d_{ab}^{j} = x_{aj} - x_{bj} \tag{17}$$

After that, a preference function H_j is assigned to each one of the criteria. This allows the user to know the preference of alternative *a* over alternative *b* for criterion *j*, and it is usually denoted as $P_j(a,b)$ (Eq. (18)). Consequently, from the deviation matrices, it is possible to generate the corresponding preference matrices.

$$P_j(a, b) = H_j\left(d_{ab}^{j}\right) \tag{18}$$

Brans and Vincke (1985) and Brans et al. (1986) defined six different preference functions (Fig. 4). As can be deducted From Fig. 4, the usual criterion, in which there is a strict preference for the alternative with the highest performance for criterion *j*, does not require the definition of any parameter, and it will be used, as the main example, in this chapter.

The next step involves estimating the global preference index $\pi(a,b)$ (Eq. (19)):

$$\pi(a, b) = \sum_{j=1}^{m} w_j \cdot P_j(a, b) \tag{19}$$

In Eq. (19), *m* is the number of criteria and w_j is the weight or relative importance of each *j*th criterion; the sum of all the weights is equal to 1. The global preference index ($\pi(a,b)$) varies between 0 and 1, and it measures the level of preference of alternative *a* over alternative *b*, after considering all the criteria or indicators.

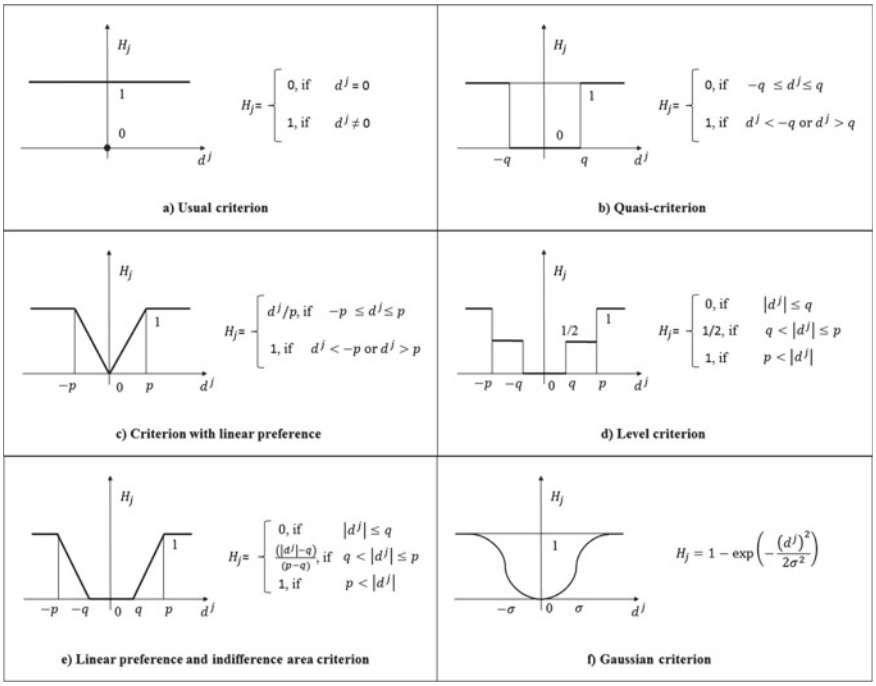

Fig. 4 Preference functions for PROMETHEE. *Source* own based on Brans et al. (1986)

Then, the leaving flow, ϕ^+, (also known as outgoing or positive outranking flow) as well as the corresponding entering one, ϕ^-, (incoming or negative outranking flow) are calculated for each alternative a (Eqs. (20) and (21), respectively (Behzadian et al. 2010)).

$$\phi^+(a) = \frac{1}{n-1} \cdot \sum_b \pi(a, b) \tag{20}$$

$$\phi^-(a) = \frac{1}{n-1} \cdot \sum_b \pi(b, a) \tag{21}$$

In Eq. (20) and in Eq. (21), b runs through all possible alternatives. The higher the value of ϕ^+ and the lower the value of ϕ^-, the better is alternative a. PROMETHEE I is based on the leaving and entering flows. In other words, if alternatives a and b present the same values for both ϕ^+ and ϕ^-, it can be said that they are equally good. If alternative a presents a higher value for $\phi^+$and a lower value for ϕ^- than alternative b, a outranks b. If alternative a obtains a higher value for ϕ^+ than b and, at the same time both present the same ϕ^-, it can be said that a is also better than b. The same is also true if a and b adopt the same value for ϕ^+, and alternative a presents a lower ϕ^-. In all other possible cases, PROMETHEE I does not allow the user to compare alternatives *a* and *b* extracting firm conclusions on what is the best option. This problem is solved with the implementation of an additional step (PROMETHEE II), in which a net flow (ϕ) is calculated for each alternative (Eq. (22)).

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{22}$$

Now alternative *a* outranks alternative *b* if $\phi(a)$ is higher than $\phi(b)$ and they present the same performance if their net flows coincide.

2.6 Utility Method: MIVES

MIVES is a relatively recent MADM method developed by researchers from three Spanish institutions (Technical University of Catalonia, University of the Basque Country and Labein-Tecnalia) (Aguado et al. 2006). MIVES was initially proposed for selecting among different alternatives according to sustainability objectives in the construction sector. Nevertheless, it can be used to solve other type of multi-criteria problems. After defining the problem to be solved, MIVES is based on the construction of a requirement tree. This tree is a scheme that is usually made up of three disaggregation levels (requirements, criteria and indicators), although it is possible to increase or decrease the number of levels depending on the complexity of the problem. The reader can find in Fig. 5 the requirement tree for the case study described in Sect. 3.

The first two disaggregation levels (requirements and criteria) serve to structure the problem, facilitating its understanding and subsequent resolution. However, the real characteristics of each alternative are assessed throughout the indicators (an indicator is equivalent to the term “criterion” in most MADM methods). In the following step, one value function is defined for each *j*th indicator. Equation (23) is used for such a purpose. Value functions transform the different units of the indicators into a common and dimensionless parameter, usually known as value or level of satisfaction (V_j). This value varies between 0 and 1, the worst and best possible performances, respectively.

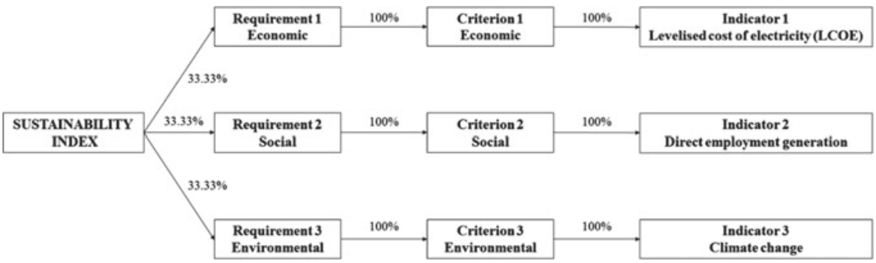

Fig. 5 Requirement tree for the case study described in Sect. 3

$$V_j = \frac{1 - \exp\left(-m_j \cdot \left(\frac{|x_j - X_{j,min}|}{n_j}\right)^{A_j}\right)}{1 - \exp\left(-m_j \cdot \left(\frac{|X_{j,max} - X_{j,min}|}{n_j}\right)^{A_j}\right)} \quad (23)$$

In Eq. (23), x_j is the value that the alternative under assessment adopts for indicator j, measured in the corresponding real units; $X_{j,min}$ and $X_{j,max}$ are the input values for indicator j linked to the minimum (0) and maximum (1) levels of satisfaction, respectively. Finally, n_j, m_j and A_j are shape parameters that allow the user to define linear, concave, convex and S-shaped geometries (Fig. 6). Value functions, like indicators, can be increasing or decreasing. Increasing are those in which a higher input value (x_j) is associated with a higher level of satisfaction (V_j). Under these circumstances, $X_{j,max}$ is higher than $X_{j,min}$. Nevertheless, the opposite is true for decreasing value functions (indicators).

The next step in MIVES consists of establishing the weights for the requirements (wr_j), criteria (wc_j) and indicators (w_j). It is important to note that the sum of the weights of all the elements belonging to the same branch of the requirement tree is equal to 1 (or 100%, in percentage). If there is only one element, for example only one

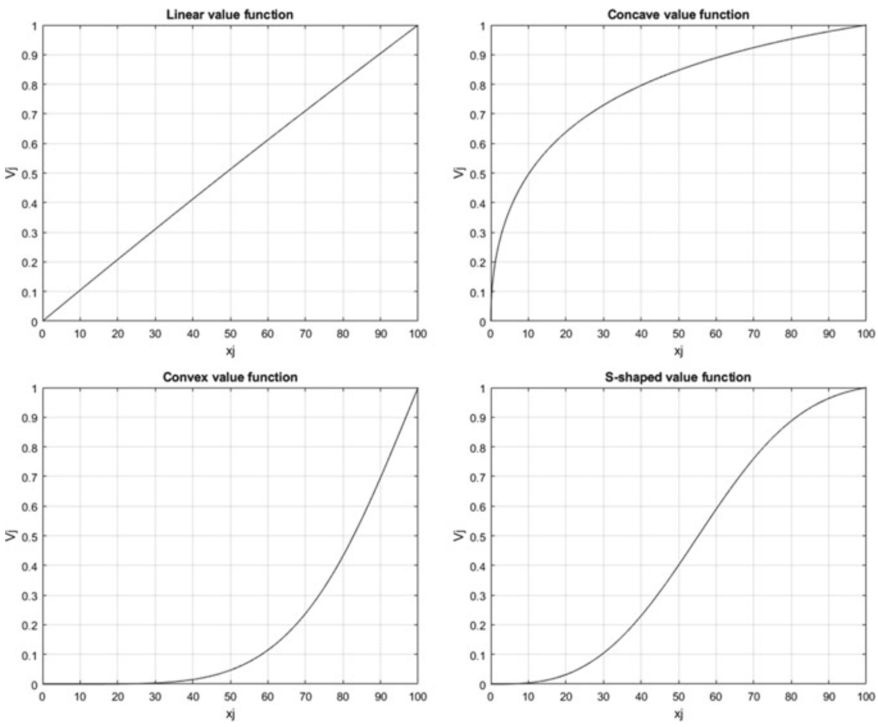

Fig. 6 Examples of linear, concave, convex and S-shaped value functions for increasing indicators, $X_{j,min} = 0$ and $X_{j,max} = 100$

indicator belonging to certain criterion, its weight is directly 1 (or 100%). There are different options for defining the weights. The easiest one is direct allocation based on expert judgement. This is usually a good alternative in cases where the number of elements to be pondered is reduced. Nevertheless, as the number of requirements, criteria or indicators increases, so does the possibility of inconsistencies and other potential problems. Consequently, the application of more sophisticated techniques such as AHP are recommended. Finally, the global performance, usually known as the sustainability index (*SI*), of each alternative is obtained by using Eq. (24), being n the number of indicators on the requirement tree.

$$SI = \sum_{j=1}^{n} wr_j \cdot wc_j \cdot w_j \cdot V_j \tag{24}$$

Once again, *SI* falls within the interval [0, 1], and the higher its value is, the better the performance of the alternative.

3 Case Study: Non-renewable and Renewable Power Plants

The 6 MADM methods described in the previous section were applied to the same case study. It consists of assessing the global sustainability of three non-renewable and three renewable types of power plants. In particular, coal, natural gas and nuclear power systems, as well as solar photovoltaic, onshore wind and biomass alternatives were considered. They were assessed throughout three criteria or indicators, each of them belonging to one of the basic sustainability pillars or dimensions (economic, social and environmental).

The levelised cost of electricity (LCOE) was the criterion selected from an economic point of view. It takes into account both lifetime energy costs and production (Cartelle Barros et al. 2016), including the cash flows derived from investment, operation and maintenance, fuel supply, and decommissioning operations. Its units of measurement are €/MWh. Similarly, on a social level, the direct job creation (DJC) generated during the construction, installation, manufacturing, operation and maintenance, decommissioning and fuel procurement stages was analysed (Cartelle Barros et al. 2017). It is measured in job-years/MWh. Finally, from an environmental perspective, the climate change potential (including biogenic carbon) (CCP), was the criterion selected (Cartelle Barros et al. 2020a, b). A cradle-to-grave approach was adopted, with some minor exceptions explained in Cartelle Barros et al. (2020a, b). The units are kg of $CO_{2\text{-eq}}$./MWh. Although, these three indicators are quite relevant for achieving sustainability, the reader should bear in mind that there are other criteria that must have been considered for a really deep analysis. Nevertheless, the inclusion of more criteria or indicators would complicate the comparisons among the different MADM methods, one of the objectives of this chapter. This is the main reason why the authors decided to include a reduced number of sustainability indicators/criteria.

Despite this, Table 3 shows a list of potential indicators for comprehensive sustainability assessments in the energy sector. It is important to note that there can be partial or total overlaps among some of these potential criteria. On the other hand, there can be some indicators that are almost exclusive to certain types of power plants. Therefore, at the time of selecting indicators for solving a case study, it is important to avoid repetitions and overlaps (Shaaban and Scheffran 2017), since they can lead to biased results. Furthermore, a large number of criteria is not desirable, as this complicates the decision-making process (data-intensive search, complexity of

Table 3 Potential indicators/criteria to be considered for sustainability assessment in the energy sector

Sustainability criteria/indicators for the energy sector			
Economic	Social	Environmental	Others
Energy payback time	Social acceptability	Climate change	Efficiency
Life cycle costs	Job creation	Eutrophication	Capacity factor
Capita cost	Population displacement	Acidification	Maturity
Levelised cost of electricity (LCOE)	Impact on cultural heritage	Photochemical ozone creation	Availability
External costs	Reduction of arable land	Ozone layer depletion	Capacity
Initial investment	Total working time	Abiotic depletion	Lead time
Feed-in tariff rate	Reduction of woodland	Land use	Supply diversification
Operation and maintenance costs	Community development	Water consumption	Average electricity generation
Profitability	Impact on education	Emissions (CO_2, CO, SO_x, NO_x, O_3, Pb)	Energy security
Willingness to pay	Improvement of health conditions	Particulate matter	Reliability
Subsidies	Gender equality	Ash	Institutional alignment
Present worth ratio	Staff appropriate training	Noise	Availability of support infrastructure
Net present value	Safety	Dust emissions	Technical losses
Internal rate of return	Staff salary	Impact on local ecosystems	Compatibility
Cost–benefit ratio	Creation of a local industry	Deforestation rate	Disruptions
Financing risk	Impact on tourism	Solid waste	Outages duration
	Severe accidents	Ecotoxicity (fresh water and marine water)	Natural disaster impact

(continued)

Table 3 (continued)

Sustainability criteria/indicators for the energy sector			
Economic	Social	Environmental	Others
	Disparities	Chemical waste	Exergy losses
	Traffic changes	Radioactive waste	Adjustable capacity
	Work quality		Resource potential
	Citizen participation in decision making		Construction time
	Local income		Service life
			Terrorist objective potential
			Fuel sensitivity

Source own based on the existing literature (Bachmann 2013; Backes et al. 2021; Dombi et al. 2014; Hacatoglu et al. 2015; Hadiyanto et al. 2019; Liu et al. 2021; López-González et al. 2019; Mohamed et al. 2020; Nagarkatti and Kolar 2021; Sedghiyan et al. 2021; Shaaban and Scheffran 2017; Shaaban et al. 2018; Stougie et al. 2018; Wu et al. 2018)

the calculations, among other potential problems). It is necessary to find a balance between the number of the indicators and the depth of the assessment (Shaaban and Scheffran 2017).

On the other hand, the reader can find in Table 4 the values that each alternative adopts for the different criteria. Those values are a proposal made by the authors based on the studies performed by Cartelle Barros et al. (2016, 2017, 2020a, b). Values cannot be said to be country-specific. In a similar line, they do not belong to real and specific power plants. They must be understood as common values for countries with mature technology.

On the other hand, an equal weightage was assumed, although small differences could have been established. As previously indicated, a value of 0.5 was defined for v (VIKOR) and the usual criterion (Fig. 4) was selected for PROMETHEE, in the first instance. Nevertheless, for MIVES, four different cases have been considered at the time of defining value functions. In the first case, linear value functions were

Table 4 Input values for the three criteria considered in this study

Power system	LCOE (€/MWh)	DJC (job-years/MWh)	CCP (kg $CO_{2\text{-eq.}}$/MWh)
Coal	65	0.00042	1100
Natural gas	90	0.00028	500
Nuclear	70	0.00021	5
Solar photovoltaic	120	0.00097	70
Onshore wind	85	0.00034	8
Biomass	100	0.00096	40

Source own based on Cartelle Barros et al. (2016, 2017, 2020a, b)

Table 5 Parameters for the value functions. The parameters for CC are partially based on Cartelle Barros et al. (2020a, b)

Param	Case 1 (linear)			Case 2 (convex)			Case 3 (concave)			Case 4 (authors' proposal)		
	LCOE	DJC	CCP	LCOE	DJC	CCP	LCOE	DJC	CCP	LCOE	DJC	CCP
$X_{j,min}$	200	1e-4	1200	200	1e-4	1200	200	1e-4	1200	200	1e-4	1200
$X_{j,max}$	25	1e-3	10	25	1e-3	10	25	1e-3	10	25	1e-3	10
n_j	182.5	1.9e-4	1081	200	1e-3	1200	200	1e-3	1200	105	5.5e-4	900
m_j	0.01	0.01	0.01	0.1	0.1	0.1	1	1	1	0.4	3	0.1
A_j	1	1	1	6	6	6	0.6	0.6	0.6	3.5	2	3.5
Trend[a]	D	I	D	D	I	D	D	I	D	D	I	D

[a]D: decreasing, I: Increasing

constructed. Therefore, an increase or decrease in the level of satisfaction (V_j) is always proportional to the variation experienced by the corresponding input value (x_j). The second case can be considered highly demanding, since convex value functions were used. In other words, the level of satisfaction (V_j) declines rapidly as the input values (x_j) moves further away from $X_{j,max}$. The third one is just the opposite. Concave value functions were defined for the criteria. Consequently, the value (V_j) grows considerably as the input value (x_j) moves away from $X_{j,min}$. The last one is a proposal made by the authors, in which different geometries were defined for the indicators. Table 5 includes the parameters used for generating the value functions in the four cases.

4 Results and Discussion

The reader can find in Table 6 the numerical results obtained with each one of the MADM methods for the six types of power systems analysed in this study. Similarly, Table 7 includes the positions that each type of power plant occupies in the rankings generated with the different MADM methods, being 1 and 6 the best and worst positions, respectively.

The results presented in Tables 6 and 7 can be analysed from different angles. First, they can be commented in terms of the sustainability contribution to the energy sector. In this regard, caution should be exercised in drawing conclusions, since only three criteria from the total set of indicators (Table 3) were studied. Despite this, it is still interesting to look at the results. It is important to remark that no alternative is always the best, regardless of the MADM technique used. In fact, three different power plants (biomass, nuclear and onshore wind) occupy the first position at least one time. Biomass-fired power plant outranks the remaining alternatives in 6 of the 9 rankings. Moreover, it is classified second and third in all other rankings.

Table 6 Numerical results for the different MADM methods

Methods and results	Power plants					
	Coal	Natural gas	Nuclear	Solar photovoltaic	Onshore wind	Biomass
SAW (A_i)	0.4792	0.3403	0.7150	0.5377	0.5801	0.5882
AHP	0.1172	0.0834	0.2708	0.1538	0.2044	0.1704
TOPSIS (S_i)	0.2263	0.4527	0.6490	0.7952	0.6828	0.8625
VIKOR (Q_i)	0.9599	0.8734	0.6807	0.6668	0.4916	0
PROMETHEE II (ϕ)	0.0667	-0.4667	0.2	-0.0667	0.2	0.0667
MIVES (SI) Case 1	0.4059	0.4744	0.6229	0.7919	0.6432	0.8347
MIVES (SI) Case 2	0.0722	0.0355	0.3904	0.5239	0.3609	0.5551
MIVES (SI) Case 3	0.6257	0.7149	0.7588	0.8991	0.8060	0.9254
MIVES (SI) Case 4	0.4397	0.2874	0.5803	0.6698	0.6337	0.7464

Table 7 Rankings of alternatives according to the different MADM methods

Methods and ranking	Power plants					
	Coal	Natural gas	Nuclear	Solar photovoltaic	Onshore wind	Biomass
SAW	5	6	1	4	3	2
AHP	5	6	1	4	2	3
TOPSIS	6	5	4	2	3	1
VIKOR	6	5	4	3	2	1
PROMETHEE II	2	4	1	3	1	2
MIVES, Case 1	6	5	3	2	4	1
MIVES, Case 2	5	6	3	2	4	1
MIVES, Case 3	6	5	4	2	3	1
MIVES, Case 4	5	6	4	2	3	1

Consequently, biomass appears as a promising option according to the three indicators considered in this study. There are several reasons for this. Biomass power systems are, to a certain extent, similar to other thermal power plants but, in this case, using a fuel with a lower calorific value. This results in slightly higher costs than non-renewable alternatives since a greater amount of fuel is needed for achieving the same generation of electricity. Despite this, its costs are still under the ones for solar photovoltaic. At the same time, this usually leads to a greater direct job creation, in particular, during the fuel procurement stage. To this must be added that biomass is usually considered as carbon neutral, at least, under certain consumption and replanting scenarios; obtaining relatively good results in terms of climate change potential. Nevertheless, more and more recent studies are questioning its carbon neutrality. Even if it is possible to assume that biomass hardly contributes to global warming in comparison with other thermal power plants, it clearly causes a planet deterioration when other environmental impacts come into play. In other words, the inclusion of indicators such as acidification, eutrophication, or land use, among others, will heavily penalise biomass (Cartelle Barros et al. 2020a, b).

According to Tables 6 and 7, coal and natural gas power plants represent the opposite case to biomass. With only one exception (coal in the PROMETHEE II ranking), they always occupy the last two positions in all the classifications. Their contribution to global warming is one of the main reasons for this. This situation would be exacerbated if more environmental impacts are included, especially for coal (Cartelle Barros et al. 2020a, b). Furthermore, their direct employment generation is not comparable to that of the best alternatives. This is due to the high capacity factors they can achieve in contrast to most renewables. That is, coal and natural gas power plants present reasonable direct job creation figures by installed capacity. Nevertheless, when electricity production is considered, the capacity factor makes the results considerably worse (Cartelle Barros et al. 2017). The reader should bear in mind that the inclusion of indirect and induced employment generation (Markandya et al. 2016; Mu et al. 2018; Tourkolias et al. 2009) can considerably affect the results as well as the rankings presented in this chapter. On the other hand, the lower direct labour requirement to generate each MWh partly explains coal and natural gas good economic results.

Nuclear, solar photovoltaic and onshore wind alternatives are usually placed in an intermediate zone between the worst and best power systems. Nuclear is a mature technology that is very low intensive in terms of fuel consumption. At the same time, its capacity factor usually varies between 70 and 90%. These facts explain both the LCOE and direct job creation results. Unlike coal and, to a lesser extent, natural gas power plants, the inclusion of more environmental indicators should not penalise nuclear too much. However, nuclear power plants often suffer problems such as cost overruns or construction delays, reducing investor interest (Ahmad and Ramana 2014). Adding new criteria to assess those aspects would worsen this alternative. Similarly, an indicator to assess the potential impacts derived from accidents would also harm nuclear. The NIMBY phenomenon (not in my backyard) could also penalise this power system (Uji et al. 2021; Wu et al. 2021), in particular if reliable information is not conveyed to the population (Dai et al. 2019).

Solar photovoltaic is always between second and fourth positions. Although it is a renewable alternative, its contribution to global warming is not negligible. During its operation it does not generate greenhouse gases. Nevertheless, the manufacture, transport, installation and dismantling stages of the solar panels does contribute to this environmental impact. As other renewables such as onshore and offshore wind, solar photovoltaic depend on natural phenomena (in this case solar radiation), which severely limits its electricity production. In fact, its capacity factor is usually below 30%. This explains, in part, its performance both economically and socially. Moreover, the consideration of other criteria such as uncertainty in generation or variability of electricity supply (Cartelle et al. 2015), among others, is likely to reduce its performance. Finally, onshore wind has been clearly penalised by its low direct job generation. There is a widespread belief that renewables always generate more direct employment than non-renewables (Cartelle Barros et al. 2017). Nevertheless, onshore wind is a mature enough technology that does not require a large labour force (Cartelle Barros et al. 2017). It is often economically competitive, even cheaper than many non-renewable options under certain conditions. Despite this, onshore wind farms tend to average slightly higher costs than nuclear or coal power plants (Cartelle Barros et al. 2016). The analysis of criteria such as social acceptance or impacts from accidents as well as the inclusion of additional environmental impact categories should improve its score. Otherwise, its dependence on wind could have the opposite effect.

The results presented in Tables 6 and 7 can be useful since they can lead the reader to reflect on certain widely spread beliefs that may be erroneous. Nevertheless, it is important to remark that they are not enough to stablish a definitive ranking. More criteria and types of power plants must be analysed to achieve such a goal. Furthermore, uncertainty should also be modelled since there can be important variations due to fuel quality or technological maturity, among many other issues.

On the other hand, the results can be also analysed from a methodological point of view. There is no MADM technique that is best suited to all multi-criteria problems. In fact, selecting the most appropriate MADM method for a specific application can be considered a multi-criteria decision making problem in its own right (Danesh et al. 2017). Many authors have assessed and compared various MCDM techniques at the time of solving different real problems (De Brito and Evers 2016; Hajkowicz and Collins 2007; Ho et al. 2010; Penadés-Plà et al. 2016), and all of them present both advantages and disadvantages.

From Table 7, it is clear that SAW and AHP generated almost the same classifications. In fact, the only difference is in the positions occupied by onshore wind and biomass that are exchanged. This seems to be reasonable, since, in this particular case, the two methods are similar. This is due to the fact that only quantitative indicators were assessed, and consequently, comparison matrices are not strictly necessary at the time of using AHP. As indicated in Sect. 2.2, a normalisation process can be carried out instead. This is not the first time that SAW and AHP provide similar results when solving the same problem. One of the main advantages of SAW is its ease of calculation (Siksnelyte-Butkiene et al. 2021). Nevertheless, this method can provide illogical results that do not represent the real situation as pointed out by Noryani et al. (2018). Consequently, a critical analysis of the results is always recommended (Siksnelyte-Butkiene et al. 2021). Furthermore, it is a compensatory technique and the only parameters to be defined are the weights of the criteria. Therefore, it is possible to say that, to a certain extent, subjective assumptions are required. However, this is something common to most MADM methods.

AHP can also be considered as a simple technique. It allows the user to study both quantitative and qualitative data in a simple way. In fact, when quantitative data is limited, AHP appears as one of the most promising options, since expert opinions can be used to perform the evaluation (Danesh et al. 2015). This advantage can also be seen as a disadvantage, as the method is affected by subjectivity. Another positive aspect of AHP is that it allows for some level of inconsistency in the assessment, as long it is acceptable (Danesh et al. 2015). However, this can lead to an undesirable situation: repetition of the comparisons if the consistency ratio is over the limit (Ho et al. 2010). On the other hand, AHP can be affected by the rank reversal problem (Danesh et al. 2015). In other words, adding or removing alternatives can considerably alter, even reverse, the original classification. Moreover, AHP can be time-consuming and difficult to implement if more than one decision maker participate and discrepancies among them appear (Ho et al. 2010; Siksnelyte-Butkiene et al. 2020). In a similar line, this method can become very tedious if the number of criteria to be compared in pairs is high (over 10 according to Danesh et al. (2015)). As is the case with SAW, AHP also requires a verification of the results obtained (Siksnelyte-Butkiene et al. 2021). In the case study considered in this chapter, the results provided by SAW and AHP turned out to be quite logical with the exception of nuclear energy. It seems reasonable to think that nuclear should have less of an advantage over renewables, since it should be more clearly penalised by its low direct job creation. Despite this, SAW and AHP resulted to be reasonably acceptable methods.

TOPSIS and VIKOR are distance-based methods. It is therefore logical that they would provide rankings in close proximity, as was the case in this study. The only difference relies on solar photovoltaic and onshore wind alternatives that occupy second and third positions in TOPSIS, while the opposite is true for VIKOR. Their classifications are similar to those provided by SAW and AHP, with the main exception of nuclear power plants. This power system was surpassed by renewables when distance-based methods were applied. VIKOR and TOPSIS are both compensatory methods and they need a normalisation step as part of their calculation processes. They are relatively simple techniques that have been designed to work with quantitative data, being problematic the assessment of qualitative criteria or indicators. One common problem to both methods is that they can experience the rank reversal issue (Danesh et al. 2017). TOPSIS is based on the Euclidean distance and, consequently, negative and positive values do not alter the calculations (Siksnelyte-Butkiene et al. 2020, 2021). Another negative feature of TOPSIS is that a strong deviation in one single indicator from the ideal solution greatly affects the results. Therefore, this method is particularly valid when the values that the alternatives adopt for the criteria are close to each other (Siksnelyte-Butkiene et al. 2020, 2021). In contrast to TOPSIS, VIKOR requires the definition of parameter v that measures the importance of the distances from the positive and negative ideal solutions. According to Siksnelyte-Butkiene et al. (2021), the normalisation process could considerably affect VIKOR results. In general, it can be stated that the results provided by these two techniques seem to be adequate. However, this may no longer be true if more criteria and alternatives were analysed.

PROMETHEE, without being an excessively complex technique, can be more intricate for the user than previous methods. Therefore, it is more oriented to the use by experts in the MCDM field (Siksnelyte-Butkiene et al. 2020). Nevertheless, complexity is subjective and not all authors think in the same way (Danesh et al. 2017). It was originally developed to work with quantitative data and, in contrast to other methods considered in this study, it does not need a normalisation process. However, it is based on the use of preference functions which, to some extent, is similar to normalisation. Consequently, this method is also affected by subjectivity (Siksnelyte-Butkiene et al. 2021), since the user has to define a preference function for each criterion (in addition to weights definition). Preference functions are a way of establishing threshold values for the assessment of criteria/indicators, something that many methods do not allow (Danesh et al. 2017). It also suffers the rank reversal problem (Danesh et al. 2017). It is the only method that has generated ties among the alternatives (Tables 6 and 7). In fact, nuclear and onshore wind occupy the first position, while coal and biomass power plants are second in the ranking. Therefore, in this particular case, PROMETHEE proved to be less sensitive in the assessment than the other techniques. The position of coal is particularly striking. Although it is the cheapest technology, its direct employment generation is far from the best alternatives and, at the same time, it is the worst power system in terms of climate change, with a big difference compared to the rest. This may be due to the use of the usual criterion (Fig. 4) for all the indicators. A sensitivity analysis has been carried out to check this issue. For reasons of length, in each scenario, the same type of preference function was defined for all the criteria, although it would have been possible to consider alternative combinations. Similarly, it would have been possible to analyse hundreds or thousands of additional scenarios, modifying the values of the parameters associated with each preference function (Fig. 4). Nevertheless, such an analysis is completely out of the scope of this chapter. The reader can find in Table 8 an example of the positions that the alternatives occupy when different preference functions were defined.

If the results from Tables 7 and 8 are compared, it is clear that preference functions can considerably alter the results provided by PROMETHEE, at least for some

Table 8 Positions of the alternatives in the Rankings according to different preference functions for PROMETHEE II

Alternatives	Preference function				
	Quasi-criterion	Linear preference	Level criterion	Linear with indifference	Gaussian
Coal	5	5	5	5	5
Natural gas	6	6	6	6	6
Nuclear	2	3	2	2	2
Solar photovoltaic	3	4	3	3	3
Onshore wind	4	2	4	4	4
Biomass	1	1	1	1	1

alternatives. Now, coal power plants do not occupy the second position in the classifications, which seems to be more reasonable. Nuclear does not lead the rankings, although it is well positioned. Biomass, now, is always the best alternative, something that also happened whit VIKOR, TOPSIS and MIVES. In this line, natural gas-fired power plants are always at the bottom of the rankings, a fact common to all methods (fifth or sixth positions). It can be concluded that, taking into account the results provided by all the techniques, the use of the usual criterion did not prove to be the best option for the problem here presented. Nevertheless, all other preference functions generated similar and robust results.

Regarding MIVES, it is the only method that is not affected by the rank reversal problem. This is due to the fact that the values for $X_{j,min}$ and $X_{j,max}$ do not have to coincide with the minimum and maximum values adopted by the alternatives under assessment, for each criterion *j*. If these extreme values are appropriately defined, the inclusion/exclusion of alternatives do not affect the scores obtained in previous assessments. Although this could be done in other methods, it is not the norm. In other words, when the decision maker is creating the model, at the time of defining $X_{j,min}$ and $X_{j,max}$, more alternatives than the ones that are going to be assessed, should be considered. This means that each MIVES model can be used for solving similar problems, without the necessity of modifying value functions. In fact, the only modifications that should be necessary are those that bring a change in the decision-maker's thinking about what minimum and maximum levels of satisfaction should be. Examples of this can be the emergence of new technologies or deviations due to passage of time. MIVES also allows the user to establish threshold values that impede the assessment of an alternative that adopts excessively poor values for certain indicators. On the other hand, unlike most MADM methods, this technique also allows the decision maker to consider non-linearities in the assessment, by defining value functions with different geometries (Fig. 6). Nevertheless, MIVES is also affected by subjectivity and its application can be difficult if several decision-makers are involved and they do not reach an agreement on value functions. This can be partially solved by adopting a probabilistic approach (Cartelle Barros et al. 2016) or by considering different scenarios, as was the case here.

Regarding the results, MIVES appeared to be a robust method, since the ranking is almost the same for the four cases, although the corresponding sustainability indices and the differences among them vary. Biomass always occupies the first position, while coal and natural gas power plants resulted to be the worst options. These results are in line with those provided by TOPSIS and VIKOR. Finally, MIVES is a method with certain peculiarities that set it apart from the resto of the MADM techniques considered in this chapter. Although, it also presents disadvantages, its robustness and wider scope of application makes it a technique with great potential for the successful resolution of many kinds of multi-criteria problems (Carral et al. 2020; Cartelle Barros et al. 2018, 2020b; Cuadrado et al. 2015; del Caño et al. 2012, 2016; Josa et al. 2021; San-José et al. 2007).

5 Conclusions and Future Developments

In this chapter the sustainability assessment of renewable (solar photovoltaic, onshore wind and biomass) and non-renewable (coal, natural gas and nuclear) power plants was addressed. Three criteria were considered for such a purpose: levelised cost of electricity, direct job creation and climate change potential (including biogenic carbon). Each one of these indicators belongs to one of the basic dimensions or pillars of sustainability: economic, social and environmental. The figures that each power plant adopts for the criteria can be considered as typical values for countries with mature technology. In fact, they are a proposal from the authors based on the existing literature. In all cases, the different life cycle stages of all types of power systems were taken into account. Since, there is no power plant that achieves the best results for the three criteria, different multi-attribute decision making (MADM) methods were employed to solve the same case study. In particular, SAW (direct scoring), AHP (pairwise comparison), TOPSIS (distance-based), VIKOR (distance-based), PROMETHEE (outranking) and MIVES (value) methods were described and applied. Their results were also presented. They were compared and discussed from two different points of view: i) sustainability approach, and ii) at a methodological level.

The main conclusions drawn from this work are:

- Sustainability assessment in the energy sector is a complex problem that requires the analysis of a considerable number of criteria or indicators. Although the three studied in this chapter are of paramount importance, from the results, it is possible to say that they are not enough to provide a realistic view of how each power plant contributes to sustainable development. For such a purpose, more economic, social and environmental indicators must be considered. Even the inclusion of a technical or functional dimension would be helpful.
- Different results were obtained when the same problem was solved with alternative MADM methods. In certain cases, the differences turned out to be negligible, while the opposite was also true. Consequently, a critical analysis of the results provided by each technique is recommended. The use of several techniques for solving the same problem is also desirable. In other words, if different techniques provide similar classifications, with insignificant deviations, the results can be considered as robust and reliable.
- In relation to the previous point, the development of hybrid techniques could also be a promising option for reducing the variability in the results.
- The six methods present both advantages and disadvantages. This means that, depending on the problem to be solved (complexity, number of criteria/indicators, quantitative and qualitative information, need to establish a hierarchical scheme, among other issues), the decision on the most appropriate technique will change.
- Those methods that present the same level of complexity provided similar results. This was also true for the techniques that belong to the same MADM sub-classification.
- All of the considered methods are, to a certain extent, affected by subjectivity.

- Preference functions can considerably influence the results generated by PROMETHEE II.
- MIVES is the only option that does not suffer the rank reversal problem. This, together with the possibility of applying the same MIVES model to similar problems with different alternatives, make this technique suitable for a wide range of different multi-criteria problems.

On the other hand, the work presented in this chapter can continue in the future. In particular, the following lines of action can be considered:

- The number of sustainability criteria/indicators needs to be increased.
- Additional renewable (offshore wind, biogas, solar thermal, hydro or wave, among others) and non-renewable (i.e. lignite, fuel oil, coal gases) alternatives should be studied.
- Alternative MADM methods (ELECTRE, MACBETH, ANP, ORESTE or COPRAS, among others) could be used to solve the same case study.
- Uncertainty must be considered and modelled. To this end, MADM methods could be modified by adopting a fuzzy approach. They can also be combined with Monte Carlo simulation.

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The New Wind Energy Boom in Spain: Are Large Companies Once Again Dominating the Market?

Raquel Fernández-González, Félix Puime-Guillén, and Raisa Pérez-Vas

Abstract Since 2019, when the wind farms derived from the installed capacity auctioned by the Spanish Ministry of Energy were installed, Spain is immersed in a new process of growth in the wind sector. In the previous wind boom, derived from the aggressive FIT system implemented by the Spanish central government, large companies were the ones dominating the market. The objective of this study is to determine, based on the calculation of concentration indexes, whether the large energy companies hold most of the wind power market share. For this purpose, a concentration study will be performed on a population sample of 646 companies, initially considering all the companies in the sector individually and then, subsequently, by groups of companies according to the corporate matrix. The result shows that more than 50% of the market share is held by the three main energy companies operating in Spain.

Keywords Wind energy · Market concentration · Wind boom · Spain

1 Introduction

Energy is an essential resource for the economic and social development of our civilization (Gürtler et al. 2019; Owusu and Asumadu-Sarkodie 2016). However, the goal of progress conflicts with the polluting nature of fossil fuels today (Bailera and Lisbona 2018; Blanco et al. 2021). This is why, for years, people have been

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working on the development and use of other energy sources, so that, in just two decades, renewable energies have gone from representing a very small percentage in the energy mix to become a reality in which we all participate, since the use of this type of technology is beneficial to life on the planet (Álvarez-Díaz et al. 2017; Creutzig et al. 2014).

From an environmental point of view, renewable energies, unlike fossil fuels, renew themselves naturally, so their use is infinite and do not produce greenhouse gases (Correia-da-Silva et al. 2020; Tolliver et al. 2020). They are, therefore, one of the few ways available to combat the increase in energy demand without aggravating the problem of climate change, and it is essential to link energy to a context of sustainability (Bean et al. 2017). Moreover, from a geopolitical perspective, these energies do not require the import of resources, since they are available to a greater or lesser extent in all countries, which will contribute decisively to a reduction of tensions in the socio-political sphere (Armijo and Philibert 2020).

For this reason, social agents (politicians, businessmen, trade unions and citizens in general) agree that a change in the world production model is essential, which implies, among other things, a much more environmentally responsible use of natural resources (Bagheri et al. 2019; Jacobson et al. 2017). This is only possible if it is supported by an energy model based on the development of renewable energies, such as those coming from the sun, wind or biomass, among other inexhaustible sources of energy (Copena et al. 2019).

In addition, the development of renewable energies is associated with a great impact on the generation of wealth and the creation of employment, because, as occurred at the dawn of the twentieth century, social and economic development in the twenty-first century is associated with electrical energy, but, in this case, produced by forces of renewable origin present in nature (Camprubí 2019).

Therefore, in order to achieve a stable future, in terms of energy supply, it is necessary to develop a sustainable resource production model, so the structure of electricity generation will change positively in favor of renewables (Solaun and Cerdá 2020). In fact, this type of energy model has started especially in those countries that are more dependent on foreign energy resources, as is the case of Spain, where nearly 50% of these resources are imported (Red Electrica Española 2021).

The exploitation of renewable energies for the production of electricity is a business activity, and as such is governed by the same rules and principles as any company operating in a freely competitive market (Fernández-González et al. 2020). They are in themselves important drivers of the economy since they directly create employment. The renewable energy sector in Spain has generated 30,000 direct jobs (Asociación Empresarial Eólica 2021a, b). Furthermore, in the long term, renewable energies will contribute decisively to a reduction in energy costs, although in the short term the cost of generation will be higher, with the importance that these items have in the profit and loss accounts of the majority of companies (Ball et al. 2016; Schlott et al. 2018).

However, in Spain, the promotion of renewable energy production has led to market failures (Simón et al. 2019). The establishment of renewable energy as a real alternative to fossil fuels began in 2008. In this year the FIT system was established, which subsidized renewable energy, converting it into a profitable sector. Regarding wind energy, in this first energy boom, the market was dominated by the large Spanish energy companies (Copena et al. 2019; Copena and Simón 2018). In 2012, the bonus system was suppressed and the growth rates of the sector, until 2019 have rebounded. This phenomenon is a consequence of the wind power auctions carried out by the Spanish central government (Fernández-González et al. 2021).

The aim of this article is to analyze whether, as in the previous period of photovoltaic energy growth, the market is dominated by the large companies in the sector. For this purpose, a concentration analysis will be carried out, calculating the individual share of each company in the sample and, in addition, the concentration will also be studied by grouping the companies according to the energy business group to which they belong. In this way, the market structure will be characterized more approximately to reality.

This study is structured as follows. Section two describes the generation and distribution process, as well as the actors involved in wind energy in Spain. Section three presents the characteristics of the Spanish wind power market and the performance of its main companies. Section four presents the methodology to be applied in section five, where the results are presented. Finally, section six discusses the conclusions derived from the analysis carried out in this study.

2 The Wind Power Market: Generation, Distribution and Players

2.1 Energy Value Chain

Electrical energy goes through a series of phases from its generation to its consumption. In this section, we will summarize what each of these phases consists of.

The process starts at the generation stage. There are basically three ways to produce electrical energy:

1. First way: basically consists of combustion processes that feed a turbine which, together with a generator, produces electric energy. For this purpose, it uses highly polluting fossil fuels such as coal, gas and oil. Recent energy policies are aimed at reducing the percentage of fossil fuel-derived energy in the energy mix.
2. Second way: nuclear energy. Its operating principle is based on exploiting the energy existing inside the atom. It is undoubtedly a clean energy, with unlimited resources, but with a major problem: the treatment of radioactive waste.
3. Third way: renewable energies. Electrical energy is produced by taking advantage of natural resources: wind, sun, rivers or forests. Its production is less efficient than the previous ones, but much less polluting than the previous ones.

Even so, due to technological advances, the efficiency related to non-polluting energies is increasing, while production costs have also decreased..

The fact of opting for one or another form of production will condition the investment to be made and, therefore, will have a different production function associated with it depending on the case. In any case, these will always be operations with a high return on investment and high financing needs, which will condition the investment towards projects with high long-term profitability, but with losses in the first few years. This is also the case for wind energy.

The energy generated, under the supervision of the electrical control center, will be transferred to the consumption centers, located at a great distance in most cases, through the high voltage transmission network, since, as we have mentioned in previous points, this is the way to guarantee lower transmission losses (Fig. 1). This transport will have a cost that will be passed on to the end consumer. The transmission grid connects with the distribution grids near the population and industrial consumption centers, but in order to transfer energy from one grid to another it is necessary to reduce the voltage of the energy being transported, so transformation substations are installed at these connection nodes.

Once the energy circulates through the distribution network, only one phase remains before it reaches the final consumer, and this energy is still at a higher voltage than usual in consumption and usually has many oscillations in its frequency that should be filtered and stabilized so as not to damage domestic and industrial appliances in their consumption. That is why, in this phase, the energy transported passes through a distribution substation.

Finally, energy in optimal consumption conditions is sold by selected distributors under free market conditions to end consumers. The prices and costs of the different phases listed above depend on the regulations and tariff regimes detailed below. The

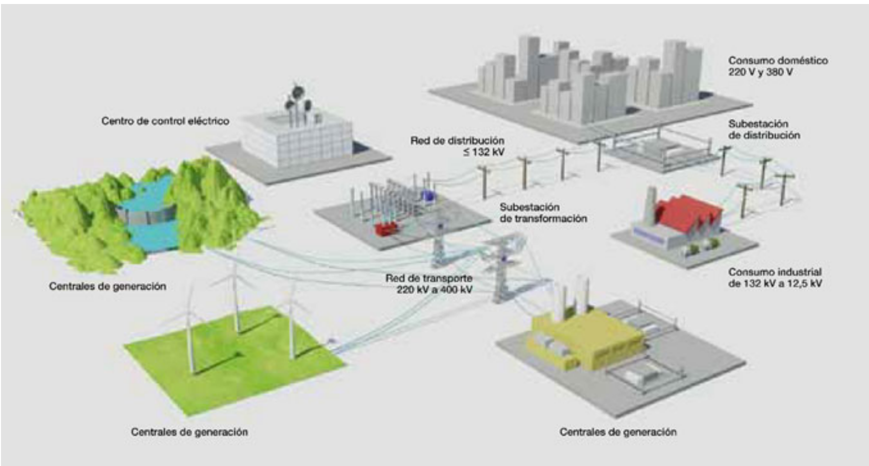

Fig. 1 Operation of the Spanish electricity market

profitability of the companies operating in the different phases and the final tariff paid by the end consumer will depend on them.

2.2 Spanish Electricity Market

The Spanish electricity market is composed of two segments: a wholesale market and a retail market. In this section the analysis will focus on the wholesale market, in which the companies in our case study operate.

In the wholesale electricity generation market, commercial negotiations for the purchase and sale of electricity and other services related to the supply of electricity take place. Likewise, this wholesale generation market consists of a physical market and a financial market (Fig. 2).

The physical market is composed of an organized market and a free market. The organized generation sector is made up of the daily market (pool), the Intraday market and the Trading markets, while the free market is made up of Physical bilateral contracts. The other type of market, the financial one, offers the possibility of entering contracts to hedge the volatility of electricity prices (contracts for differences, forward contracts, and options and futures contracts).

Within the organized market, in the daily market, electricity negotiations for the following day are carried out through the submission of electricity purchase and sale bids by market agents. The importance of this market is reflected in the fact that 85% of energy transactions are traded in it. In addition, it is the market with the greatest influence in the formation of the generation price. Thus, the organized

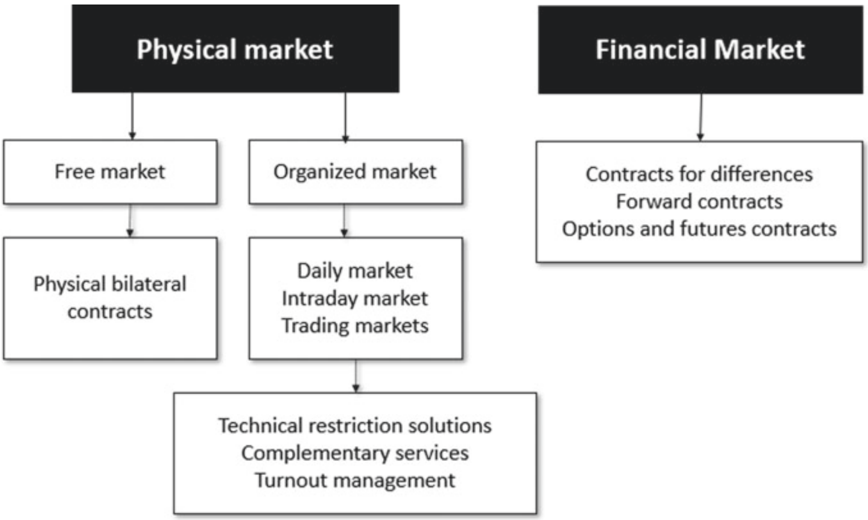

Fig. 2 Spanish wholesale market

market is where the producing agents make energy sale offers for each of the hours of the following day, while, on the other hand, the buyers make offers to acquire that energy. Companies offer their plants separately, specifying both production and price. At the same time, buyers make purchase offers, specifying both the quantity they wish to buy and the price they are willing to pay.

As a result of this process, a supply curve and a demand curve are generated for each hour of the day. The supply curve is obtained by aggregating the quantities of energy offered by the producers in ascending order of price. On the other hand, the demand curve is obtained by ordering the quantities offered by the buyers in descending order. The result of the matching of supply and demand is a combination of price and quantity, where supply and demand are equalized. At that equilibrium point, no more energy is produced, since the price demanded by the next generation unit exceeds the price that buyers are willing to pay. Thus, the equilibrium price is the price offered by the most expensive generator needed to satisfy demand (Fig. 3).

In the intraday market, adjustments in energy supply and demand that may occur after the daily market has closed are made. Thus, thanks to these balancing markets, the system can accommodate the inevitable discrepancies between actual and forecast demand, and also allows generators to optimize their operating schedules. The economic management of both the daily and intraday markets is the responsibility of the Market Operator (OMEL) (Dai et al. 2021).

As for the operating markets, these adapt the generation programs resulting from the daily and intraday markets to the technical restrictions of the high voltage transmission grid, so that the electricity supply is carried out under optimal conditions of quality, reliability and safety. (Dai et al. 2021; Imran and Kockar 2014). In addition,

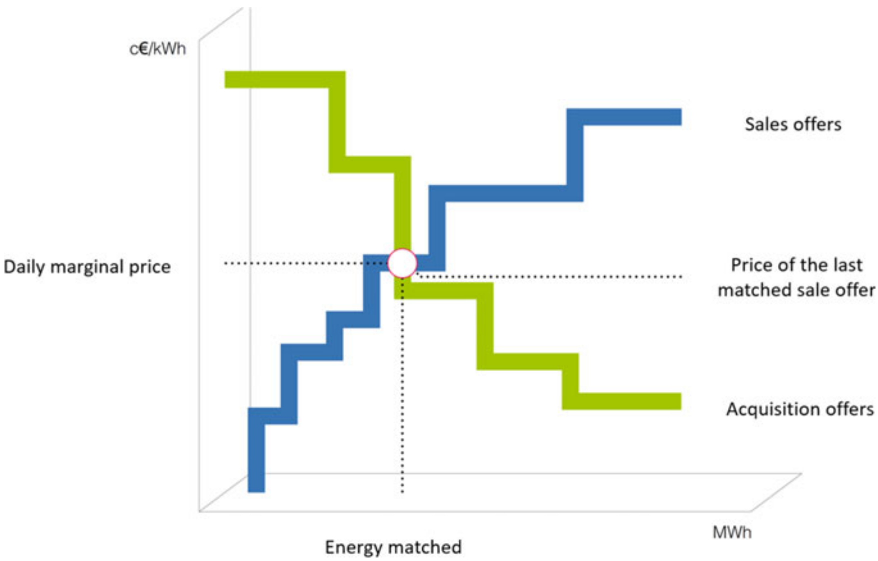

Fig. 3 Curve of the daily Spanish electricity market for each hour

the operating markets are composed of segments in charge of resolving technical restrictions, managing deviations between generation and demand due to faults in the generating groups and assigning complementary services. This type of market is managed by REE, which is the System Operator (Malvaldi et al. 2017). The operation of the Spanish electricity system is entrusted to two independent organizations, which are, on the one hand, the Market Operator and, on the other hand, the System Operator.

OMEL (*Operador del Mercado Ibérico de Energía, Polo Español, S.A.*), is the company in charge of managing both the daily and intraday markets, and is also responsible for the liquidation and communication of the payment obligations and collection rights arising from the energy contracted in the daily and intraday markets. (Shayeghi and Sobhani 2014).

As regards the technical management of the electricity system, REE (*Red Eléctrica de España*), the Spanish system operator, is in charge of performing all those functions derived from the operation of the system adjustment services, deviations produced in the electricity production market, as well as the liquidation and communication of payment obligations and collection rights arising from the system adjustment services, the power guarantee and deviations.

2.3 The Role of the Power Grid in the Market

REE was created in 1985 with the aim of taking charge of the transmission grid and the operation of the Spanish electricity system, achieving a separation between the generation and distribution of electricity. Today, with a workforce of approximately 1,500 employees, it operates both nationally and internationally, with the two main activities of the company within Spain being that of system operator and electricity transmission.

2.3.1 System Operator

REE operates in the Spanish electricity system, guaranteeing the supply of electricity and its security so that electricity flows correctly from the generation centers to the points of consumption (Valero et al. 2010). Likewise, REE, as the electricity system operator, must maintain a balance between supply and demand due to the fact that electricity cannot be accumulated in large quantities, which obliges it to forecast consumption and supervise the generation facilities and the transmission grid in real time (Garrués-Irurzun and López-García 2009).

A further function, as system operator, is the management of all electricity exchanges with other countries that are necessary to maintain or even increase the quality and security of supply. On the other hand, REE must inform the regulators of the transmission and interconnection capacity of the electricity system, as well as the interconnection needs with other electricity grids (Brey 2021). It is also responsible for analyzing all new requests for connection to the grid and limiting access to the system when there is insufficient capacity or there are risks to security of supply.

Finally, as part of its role as operator, it must manage the adjustment services, whose mission is to adapt the production programs resulting from the daily and intraday electricity markets to the quality, reliability and safety requirements of the national electricity system.

In order to implement all these activities as Electricity System Operator, REE has developed the CECOEL (Electricity Control Center of Red Eléctrica), which is in charge of providing orders for the operation of the production and transmission system to guarantee supply (Colmenar-Santos et al. 2020). In relation to this issue, REE has also developed the CECRE (Special Regime Control Center) whose objective is to integrate into the electricity system the maximum production of energy from renewable sources, especially wind energy (Shrestha et al. 2020). Thus, with the development of this center, Spain has become the first country in the world to connect all its wind farms of more than 10 MW to a control center.

2.3.2 Electric Power Transmission

REE is responsible for transporting electricity at high voltage, which requires it to manage the infrastructures that make up the transmission grid and connect the power plants where the electricity is generated with the points where it is consumed. Therefore, REE is the manager of the electricity transmission grid and operates as the sole transmission agent, owning 99% of the Spanish high voltage grid (Blanco et al. 2021; Puig-Samper Naranjo et al. 2021). The remaining 1% is owned by private companies in the sector, although REE must acquire it in accordance with Law 17/2007.

As for the transmission grid, in 2020, it will consist of nearly 44,000 km (Table 2) and more than 5,500 substations (Table 3), with REE being responsible for its maintenance and expansion as the managing body of the electricity grid (Red Eléctrica de España 2021).

3 Evolution of the Spanish Institutional Framework Applied to Wind Power Technology

In 2020, the Spanish national electricity system generated 251,399 GWh of energy, of which 54,905 GWh corresponded to wind energy. This means that 21.8% of the energy generated in Spain, and 55% of the renewable power, comes from wind energy (Red Eléctrica de España 2020a). Currently, there is no other energy of renewable origin that has such a high contribution to the energy mix. Neither hydraulic energy (12.2%), nor photovoltaic solar energy (6.1%), nor thermal solar energy (1.8%)

Table 1 Components of the average final price of energy

	Daily market	Intraday market	Daily and intraday markets	Adjustment services	Capacity payments	Interruptibility service	Final price	Final energy
January-19	62.980	-0.030	62.950	1.150	3.160	0.710	67.97	23,270.6
February-19	54.930	-0.030	54.900	1.140	3.080	0.750	59.87	20,114.9
March-19	49.350	-0.020	49.330	1.730	2.380	0.720	54.16	20,688.9
April-19	50.940	-0.050	50.890	2.560	2.410	0.770	56.63	19,484.3
May-19	48.930	-0.010	48.920	1.800	2.300	0.750	53.77	19,874.7
June-19	47.400	-0.010	47.390	1.300	2.700	0.750	52.14	19,955.3
July-19	51.960	0.000	51.960	0.810	3.250	0.690	56.71	22,669.8
August-19	45.370	0.000	45.370	1.020	2.100	0.730	49.22	21,151.5
September-19	42.590	-0.010	42.580	1.080	2.380	0.780	46.82	19,914.0
October-19	47.740	-0.020	47.720	1.390	2.340	0.770	52.22	20,151.1
November-19	43.600	-0.030	43.570	1.550	2.440	0.750	48.31	20,817.5
December-19	35.390	-0.020	35.370	2.110	3.020	0.740	41.24	20,907.5
January-20	42.060	-0.020	42.040	1.780	3.110	0.030	46.96	22,600.1
February-20	36.540	-0.030	36.510	1.880	2.980	0.030	41.40	19,846.7
March-20	28.280	-0.010	28.270	2.550	2.390	0.030	33.24	19,787.2
April-20	17.810	-0.020	17.790	5.050	2.420	0.040	25.30	16,146.9
May-20	21.700	-0.010	21.690	3.360	2.250	0.040	27.34	17,320.2
June-20	30.990	-0.010	30.980	2.240	2.760	0.040	36.02	18,287.5
July-20	35.200	-0.010	35.190	1.600	3.230	0.000	40.02	21,895.5
August-20	36.750	-0.010	36.740	2.180	2.120	0.000	41.04	20,673.3
September-20	42.740	-0.020	42.720	2.360	2.370	0.000	47.45	19,352.0

(continued)

Table 1 (continued)

	Daily market	Intraday market	Daily and intraday markets	Adjustment services	Capacity payments	Interruptibility service	Final price	Final energy
October-20	37.490	-0.040	37.450	2.950	2.270	0.000	42.67	19,552.3
November-20	42.910	-0.030	42.880	2.880	2.370	0.000	48.13	19,622.2
December-20	43.520	-0.020	43.500	2.600	3.100	0.000	49.20	20,976.2

Table 2 Extension of the REE transmission grid

Circuit Km	2016	2017	2018	2019	2020
400 kV	21.626	21.735	21.737	21.748	21.764
220 kV	19.615	19.641	19.735	19.853	19.886
150 - 132 - 110 kV	524	524	636	697	753
< 110 kV	2.025	2.035	2.075	2.067	2.078
Total	43.791	43.934	44.183	44.365	44.482

Table 3 Substations of the REE transmission gri

Número de posiciones	2016	2017	2018	2019	2020
400 kV	1.453	1.479	1.501	1.538	1.549
220 kV	3.193	3.214	3.261	3.34	3.319
150 - 132 - 110 kV	99	125	130	151	151
< 110 kV	823	853	903	922	951
Total	5.568	5.671	5.795	5.951	5.97

surpass wind energy as the leading renewable source of energy generation in Spain (Red Eléctrica de España 2020b). As a consequence of the high development of wind energy in Spain, more than 1,000 municipalities share the 1,265 existing wind farms and, their operation, has avoided the emission of 29 million tons of CO2 (Abadie and Goicoechea 2021). The growing implementation of wind energy in Spain ranks it as the country with the fifth largest wind power capacity in its territory, behind China, the United States, Germany and India (Asociación Empresarial Eólica 2021a, b).

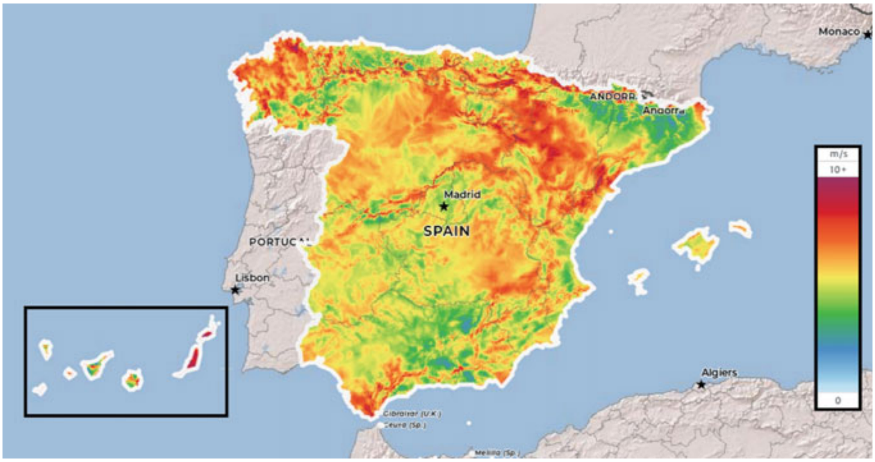

Fig. 4 Average wind speed at 100 m in Spain. *Source* (World Bank Group 2021)

Despite the appropriate climatic conditions for wind power generation (Fig. 4), it has been the institutional framework approved by the Spanish central government in the last decade of the twentieth century that gave the definitive impulse to the growth of renewable energy production in this country (Duffield 2021). This is reflected in the change that occurred in the electricity generation in Spain between 1998–2008. In 1998, more than 80% of the electricity produced in Spain was generated by three technologies: hydro, coal and nuclear power plants. Due to the strong impulse of hydraulic energy in the second half of the twentieth century, the percentage of electricity generated from the different technologies in the special regime reached 11%, with a residual presence of wind energy.

However, in 2008, wind energy was one of the most important renewable energies in Spain. This is due to the fact that its production had experienced high growth in the previous ten years, since in 1998 it produced barely 1,200 GWh, with an installed capacity of 700 MW, rising to produce more than 30,000 GWh in 2008, with an installed capacity of almost 16,000 MW. This meant a 30-fold increase in production, while in the case of installed capacity the growth was 20 times higher. The approval of Law 54/1997 on the Electricity Sector, whose objective was to increase the use of renewable energies, has had a special impact on this process. This law established the "special regime" in which renewable energies operate after its approval (Ferrer and Fernandez 1999).

The remuneration of the special regime will be differentiated from that of the Ordinary Regime thanks to the application of a premium mechanism (Marques et al. 2018). The premiums are quoted as a percentage of the average reference tariff, the determination is based on factors such as the voltage level at which the energy is delivered to the grid, the contribution to environmental improvement, primary energy savings, energy efficiency and investment costs incurred (Roldan-Fernandez et al. 2016). Through this special remuneration regime, which aims to compensate externalities not included in the price of electricity produced under the ordinary regime, the implementation of renewable energies is encouraged (Fuinhas and Marques 2012).

The positive growth trend had as a fundamental element the establishment of the Spanish feed-in tariff system, which was introduced in 1998 (Friebe et al. 2014). In addition, between 2005 and 2013, the Spanish central government boosted several aid programs for wind power generation, which attracted investors to this sector. However, both the incentives for renewable generation and the various governmental actions to support wind energy were cancelled in 2013 (Best and Burke 2018; Ziegler et al. 2018). The large transfer of public resources to the energy sector in a context of economic crisis was the reason why the Spanish government promoted this sharp change towards renewable energy (Matti and Consoli 2015; Odam and de Vries 2020).

After a period of stagnation in the sector, in 2016 and 2017 the Spanish central government approved large-scale public auctions for wind energy. The reason lies in the commitment made by Spain to the European Union (EU). By means of Directive (EU) 2018/2001, EU member countries assumed the objective that 20% of energy consumption should come from renewable sources by 2020 (Inês et al. 2020). Spain, faced with the danger of failing to comply with this agreement, awarded 500 MW

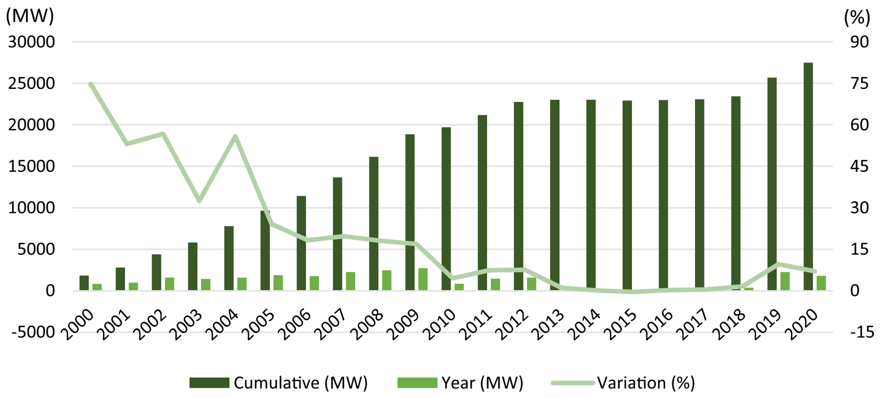

Fig. 5 Installed wind power. *Source* (Comisión Nacional de los Mercados y la Competencia (CNMC) 2021)

wind power through public auctions held in 2016 and 2017, increased this amount reaching 4,107 MW auctioned (Asociación Empresarial Eólica 2021a, b; Grashof 2021).

Following the installation of auctioned wind power, installed capacity in 2019 increased by 2,200 MW (9.4%) compared to the previous year (Fig. 5). This high growth in wind power had not been experienced since 2013. As a result, wind power approached in amount to combined cycle power, the technology that leads the energy power structure in Spain. In 2020, the year-on-year growth rate was also considerable, (7.0%) but lower than in 2019. The consequences of the Covid-19 crisis have led to a delay in the implementation of wind projects (Red Electrica Española 2021).

4 Methodology

The database used in this case study is SABI. (Iberian Balance Sheet Analysis System), an economic-financial content analysis software. This database provides information on 2,600,000 Spanish companies and 800,000 Portuguese companies classified according to economic, financial, social and availability criteria (Bureau Van Dijk Electronic Publishing group 2021). In this case study, the aim is to define a sample of Spanish companies in order to analyze their market dominance. For this purpose, the following search criteria have been used:

- Geographical location: Spain, the head office of the company may be located in any of its regions.
- CENA Code 2009 (Primary Code): 3518 - Production of electrical energy from wind power.
- Last year of accounts: 2020.
- Availability of accounts: from 2015 to 2020.

- Company status: active in at least one of the years of the 2015–2020 period.

As a result of the search strategy, a population sample of 646 companies was obtained (Table 4).

There are discrepancies between Table 4 and Fig. 6. While Fig. 6 shows that the leading regions in wind energy in Spain are Castilla y León, Aragón, Castilla-La Mancha and Galicia, whereas Madrid is irrelevant in terms of wind power generation, in Table 4 the scenario represented is different. This is due to the fact that, in Table 4, the location of the companies is based on the criterion of the establishment of the head office, not where the wind farms of the company are actually located.

Despite the fact that the population sample consists of 646 companies, through an analysis of the corporate structure, it was determined that 10.37% are investee firms whose global parent company is a large company in the Spanish energy sector. In the case of Naturgy Energy Group, S.A., there is only one company from the group in the population sample, but both Acciona, S.A. (45 companies) and EDP Energía S.A.U. (45 companies) are own a large number of participated companies (Table 5).

Therefore, two types of concentration analysis have been carried out in this study. The first is performed on an individual basis, applying the following formula to determine the market share of the company:

$$\sigma_i = \frac{x_i}{\sum_{i=1}^{n} x_i} = \frac{x_i}{x_N}, (I = 1, \ldots, n) \tag{1}$$

where x_i is the value of net sales of the company x_N is the total net sales value of the sector.

In addition, the cumulative concentration of the sector is also calculated, which reflects the rate of market dominance up to the place occupied by the corresponding company:

$$c_n = \sum_{i=1}^{n} \sigma_i = \frac{\sum_{i=1}^{n} x_i}{x_N} = \frac{x_N}{x_N}, n(I = 1, \ldots, n) \tag{2}$$

In the second concentration analysis, formulas 1 and 2 are also applied, but the difference is that the analysis is performed using the Acciona, S.A. and EDP Energía S.A.U. groups of companies. In other words, the group of companies in which each of these parent companies has an interest is considered as a single company. This analysis is carried out in order to determine the real dominance of the large energy companies in the Spanish wind energy sector.

In addition, in order to further analyze the level of market concentration, the Gini index will also be calculated. This index has a range between o and 1, with 1 representing a monopoly situation and 0 a situation of perfect competition.

$$G = \frac{N + 1 - 2\sum_{i=1}^{N} i\sigma_i}{N}$$

Table 4 Location and classification by operating income of the companies in the sample

Turnover Region	Less than 1,000,000€	From 1.000,000€ to 5,000,000€	From 5,000,000€ to 10,000,000€	From 10,000,000€ to 50,000,000€	From 50,000,000€ to 100,000,000€	More than 100,000,000€	All
Andalusia	22	2	2	1	0	0	**27**
Aragon	32	15	2	2	0	0	**51**
Asturias	8	3	2	0	1	1	**15**
Balearic Islands	1	0	0	0	0	0	**1**
Canary Islands	26	8	0	0	0	0	**34**
Cantabria	1	0	0	0	0	0	**1**
Castilla y León	34	2	1	0	0	0	**37**
Castilla-La Mancha	25	0	0	0	0	0	**25**
Catalonia	11	3	3	4	0	0	**21**
Valencian Community	7	0	0	0	1	0	**8**
Extremadura	3	0	0	0	0	0	**3**
Galicia	143	24	3	3	0	0	**173**
La Rioja	3	0	1	1	0	0	**5**
Madrid	86	49	39	24	0	2	**200**
Navarra	16	9	1	1	0	0	**27**
Basque Country	16	2	0	0	0	0	**18**
All	**434**	**117**	**54**	**36**	**2**	**3**	**646**

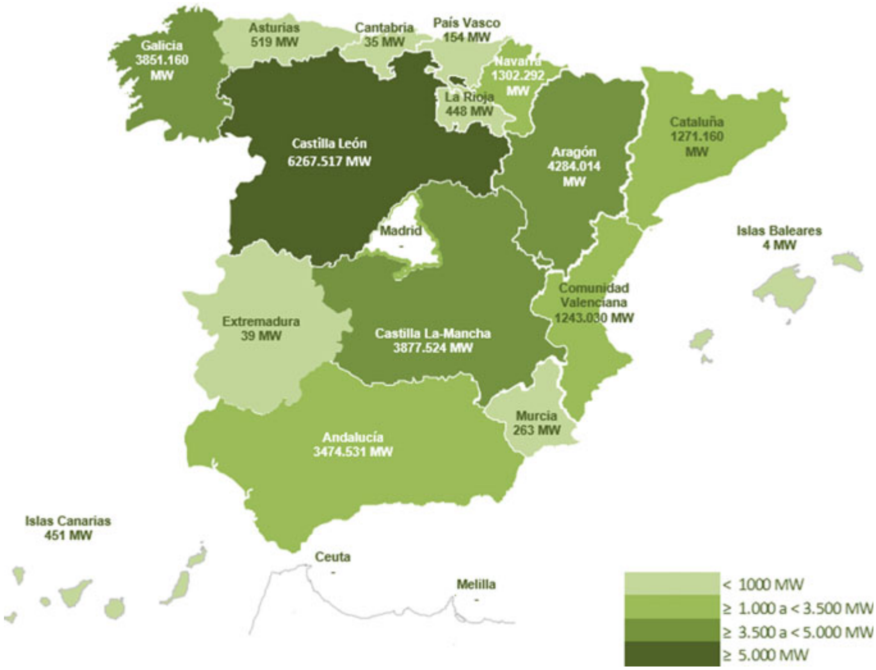

Fig. 6 Wind power installed in each Spanish region. *Source* (Comisión Nacional de los Mercados y la Competencia (CNMC) 2021)

where N is the number of companies in the market and σ_i is the market share of the i-th firm.

5 Results

Table 6 illustrates that the degree of concentration in the sector has remained practically static between 2015–2020. There is only one exception: the scenario presented in 2020. After installing the power generated from the auctions held in 2016 and 2017, the companies awarded in this tender postponed, for the most part, the construction of the wind farms to 2019, this being the last year to exercise the right to install.

Of the top 9 companies in the market, 5 are established in Madrid, 2 in Asturias, 1 in Galicia and 1 in the Community of Valencia. It is precisely the large companies that are located in Madrid. The reason does not lie in the fact that they carry out activities in that region, but in the fact that Madrid offers tax advantages not comparable to other regions. The first three companies, Naturgy Renovables S.L.U., Acciona Eólica S.L. and EDP Renovables España S.L.U. have operating revenues of more than 160 million euros, while the fourth market leader does not even reach half that figure. The net sales variable shows the same comparison. Moreover, the trend over this period

Table 5 Characterization of the energy groups of the study sample

Groups of companies	Turnover (th EUR)			Economic profitability (%)			Financial profitability (%)		
	Averigüe	Median	No. companies	Average	Median	No. companies	Average	Median	No. companies
2015									
Naturgy group	109,123	109,123	1	3.83	3.83	1	18.56	18.56	1
EDP group	11,186	6,479	21	3.20	2.86	21	15.28	8.92	21
ACCIONA group	12,745	4,225	43	48.47	2.55	45	60.80	9.62	45
Rest of the companies	3,668	1,442	218	-21.03	-0.12	350	-233.80	0.39	350
2016									
Naturgy group	113,738	113,738	1	0.57	0.57	1	3.15	3.15	1
EDP group	9,674	5,921	21	1.70	1.53	21	15.13	6.43	21
ACCIONA group	11,635	3,378	43	9.87	1.24	45	15.32	7.19	45
Rest of the companies	3,479	1,373	224	-19.72	-0.34	377	1.48	0.00	377
2017									
Naturgy group	127,161	127,161	1	1.52	1.52	1	7.95	7.95	1
EDP group	17,786	7,290	21	7.77	8.21	21	34.90	26.73	21
ACCIONA group	13,399	4,484	41	26.70	3.27	43	35.70	10.04	43
Rest of the companies	4,071	1,605	235	-1.17	0.00	416	-44.26	1.14	416
2018									
Naturgy group	146,208	146,208	1	3.10	3.10	1	16.71	16.71	1
EDP group	17,792	6,844	21	7.74	7.71	21	35.43	30.22	21
ACCIONA group	14,549	4,860	42	23.57	7.15	44	18.41	15.41	44
Rest of the companies	3,907	1,559	247	-52.94	0.00	476	-19.34	0.32	476

(continued)

Table 5 (continued)

	Turnover (th EUR)			**Economic profitability (%)**			**Financial profitability (%)**		
Groups of companies	**Averigüe**	**Median**	**No. companies**	**Average**	**Median**	**No. companies**	**Average**	**Median**	**No. companies**
2019									
Naturgy group	187,615	187,615	1	1.96	1.96	1	12.04	12.04	1
EDP group	17,571	8,648	21	8.02	7.30	21	27.59	28.85	21
ACCIONA group	14,408	4,644	43	17.78	6.84	45	32.74	12.39	45
Rest of the companies	3,686	1,168	284	-88.45	0.00	528	157.65	0.54	528
2020									
Naturgy group	265,238	265,238	1	0.52	0.52	1	3.40	3.40	1
EDP group	16,494	6,673	21	5.75	5.67	21	17.33	11.15	21
ACCIONA group	12,759	3,926	42	7.22	6.10	45	13.19	15.00	45
Rest of the companies	3,349	1,166	296	-9.52	0.00	579	348.96	0.00	579

Table 6 Concentration by individual companies in the Spanish wind energy sector, 2020–2015

Year	Position	Company Name	th EUR	%	Cumulative %
2015	1	Corporacion Acciona Eolica SL	172,822	10.34	10.34
	2	Naturgy Renovables SLU	106,946	6.40	16.74
	3	Energias Renovables Mediterraneas SA	76,391	4.57	21.31
	4	EDP Renovables España SLU	59,943	3.59	24.89
	5	Molinos Del Ebro SA	50,729	3.03	27.93
	6	Viesgo Renovables SL	44,378	2.65	30.58
	7	CYL Energia Eolica SL	31,557	1.89	32.47
	8	Esquilvent SL	30,010	1.80	34.26
	9	Parques Eolicos De Buio SL	29,501	1.71	36.03
		Rest of the companies	1,069,387	64.02	100.00
2016	1	Corporacion Acciona Eolica SL	162,998	10.33	10.33
	2	Naturgy Renovables SLU	110,181	6.98	17.31
	3	Energias Renovables Mediterraneas SA	69,926	4.43	21.74
	4	EDP Renovables España SLU	45,048	2.85	24.59
	5	Viesgo Renovables SL	44,194	2.80	27.39
	6	Molinos Del Ebro SA	42,411	2.69	30.08
	7	CYL Energia Eolica SL	29,471	1.87	31.94
	8	Esquilvent SL	28,194	1.79	33.73
	9	Acciona Eolica Del Levante SL	27,522	1.74	35.47
		Rest of the companies	1,018,540	64.52	100.00
2017	1	Corporacion Acciona Eolica SL	174,541	8.84	8.84
	2	EDP Renovables España SLU	170,043	8.61	17.44
	3	Naturgy Renovables SLU	121,934	6.17	23.62
	4	Energias Renovables Mediterraneas SA	85,530	4.33	27.95
	5	Molinos Del Ebro SA	56,097	2.84	30.79
	6	Parque Eolico La Boga SL	49,679	2.51	33.30
	7	Viesgo Renovables SL	45,087	2.28	35.58
	8	CYL Energia Eolica SL	33,430	1.69	37.27
	9	Esquilvent SL	31,307	1.58	38.86
		Rest of the companies	1,207,791	61.15	100.00
2018	1	Corporacion Acciona Eolica SL	192,991	9.39	9.39
	2	EDP Renovables España SLU	166,936	8.12	17.51
	3	Naturgy Renovables SLU	139,547	6.79	24.30
	4	Energias Renovables Mediterraneas SA	78,445	3.82	28.11
	5	Molinos Del Ebro SA	52,369	2.55	30.66
	6	Parque Eolico La Boga SL	49,318	2.40	33.06

(continued)

Table 6 (continued)

Year	Position	Company Name	th EUR	%	Cumulative %
	7	Viesgo Renovables SL	46,249	2.25	35.31
	8	Acciona Eolica Del Levante SL	34,124	1.66	36.97
	9	CYL Energia Eolica SL	33,069	1.61	38.58
		Rest of the companies	1,262,757	61.41	100.00
2019	1	Corporacion Acciona Eolica SL	194,878	8.95	8.95
	2	Naturgy Renovables SLU	182,156	8.36	17.31
	3	EDP Renovables España SLU	169,970	7.80	25.11
	4	Energias Renovables Mediterraneas SA	81,157	3.73	28.84
	5	Viesgo Renovables SL	51,518	2.37	31.20
	6	Parque Eolico La Boga SL	49,937	2.29	33.50
	7	Molinos Del Ebro SA	47,195	2.17	35.66
	8	Acciona Eolica Del Levante SL	33,016	1.52	37.18
	9	Acciona Eolica De Galicia SA	32,001	1.47	38.65
		Rest of the companies	1,336,385	61.34	100.00
2020	1	Naturgy Renovables SLU	255,317	12.14	12.14
	2	Corporacion Acciona Eolica SL	172,043	8.18	20.32
	3	EDP Renovables España SLU	167,723	7.97	28.29
	4	Energias Renovables Mediterraneas SA	76,939	3.66	31.95
	5	Viesgo Renovables SL	49,161	2.34	34.29
	6	Parque Eolico La Boga SL	48,833	2.32	36.61
	7	Molinos Del Ebro SA	31,170	1.48	38.09
	8	Esquilvent SL	30,825	1.47	39.56
	9	CYL Energia Eolica SL	30,476	1.48	41.01
		Rest of the companies	1,240,751	58.96	100.00

of time is that the difference in sales margin between the first three companies and the rest of the competitors is increasing.

The first three leading companies in the market, although they interchange their positions throughout the study period, maintain a range of market share with small variations, since their position in Table 6 fluctuates slightly. It is important to highlight the change of leadership in the sector that occurred in 2020. While in the previous four years Acciona Eólica S.L. was the company that accumulated the largest share, in 2020 it was surpassed by Naturgy Renovables S.L.U. This transition is due to the fact that Naturgy Renovables S.L.U. acquired greater power in the auctions of 2016 and 2017, so that, after the installation of different wind farms across the Spanish geography, it has positioned itself as the most important wind energy producing company in Spain. Overall, Naturgy Renovables S.L.U. acquired 667 MW of wind power through the auctions. In 2019 the company installed wind farms in the regions of Andalusia, Aragon, Castile and Leon, Navarre and Galicia. As a result, the company

Increased its business in renewable energies by up to 83%, which led to an outlay of 955 million in investments (El independiente 2019). Participation in wind energy auctions is part of the new business strategy of the company. Naturgy Renovables S.L.U., which was specialized in gas combined cycles, decided to firmly bet on the renewable energy business, specifically photovoltaic and wind energy, in view of the favorable institutional framework created by the Spanish government and the European Union, and the depletion of fossil fuels.

The strong increase in the market share of Naturgy Renovables S.L.U. is reflected in Table 7. The analysis shows that in 2020 the year-on-year variation of the Gini index doubles. The high value of the index, which exceeds the value of 0.70 throughout the period, reflects the moderate concentration that exists in the sector.

In the case of the analysis by business groups, market concentration is twenty points higher. The value of the cumulative dominance index for the first three records of the ranking shows that the large business groups accumulate more than 50% of the market share for the entire period studied (Table 8). That is, the 66 companies that are more than 50% owned by large energy companies accumulate more market power than the remaining 580 companies.

Since the middle of the twentieth century, the large companies Acciona, EDP and Naturgy have been major players in the Spanish energy market. Together with Endesa and Iberdrola, they have controlled energy production, distribution and marketing channels. In addition, they have been the leading companies in the access and promotion of technological advances in the sector (López and Cebrián 2021).

Large companies have comparative advantages over their smaller competitors. First, the initial investment required to enter the wind energy sector is a barrier to entry that is difficult to overcome for companies with a small amount of capital. Secondly, economies of scale are a positive factor that reduces the costs borne by large companies. Third, the energy auction system itself is conducive to awarding projects to large companies (Đukan and Kitzing 2021). The auction system assigns the project to the successful bidder that offers the lowest last bid, which is called the marginal price system. Consequently, this system benefits the company with the lowest costs, not the most efficient one (Espinosa et al. 2021). In addition, large companies have more liquidity to face the payment of the guarantees required by the Spanish Government to allocate installed power (around 60 €/kW) (Ministerio de Energía, Turismo y Agenda Digital 2017).

In addition, large companies have developed a strategy to grow and position themselves as dominant companies in the wind energy sector. This model consists of creating "mini-multinationals" through participation in small and medium-sized

Table 7 Gini index value calculated for individual companies in the Spanish wind energy sector, 2020–2015

Gini index	2015	2016	2017	2018	2019	2020
Value	0.71	0.71	0.72	0.73	0.74	0.76
Variation rate	-	0.00%	1.41%	1.39%	1.37%	2.70%

Table 8 Concentration by groups of companies in the Spanish wind energy sector, 2020–2015

Year	Position	Company Name	th EUR	Cumulative values	%	Cumulative %
2015	1	Acciona Group	542,274	542,274	32.44	32.44
	2	EDP Group	232,194	774,468	13.89	46.33
	3	Naturgy Renovables SLU	106,946	881,414	6.40	52.73
	4	Molinos Del Ebro SA	50,729	932,143	3.03	55.76
	5	Viesgo Renovables SL	44,378	976,521	2.65	58.42
	6	CYL Energia Eolica SL	31,557	1,008,078	1.89	60.30
	7	Esquilvent SL	30,010	1,038,089	1.80	62.10
	8	Guzman Energia SL	28,944	1,067,033	1.73	63.83
	9	Galicia Vento SL	18,491	1,085,524	1.11	64.94
		Rest of the companies	586,141	321,157,830	35.06	100,00
2016	1	Acciona Group	494,484	494,484	31.33	31.33
	2	EDP Group	201,389	695,873	12.76	44.08
	3	Naturgy Renovables SLU	110,181	806,054	6.98	51.06
	4	Viesgo Renovables SL	44,194	850,248	2.80	53.86
	5	Molinos Del Ebro SA	42,411	892,658	2.69	56.55
	6	CYL Energia Eolica SL	29,471	922,129	1.87	58.42
	7	Esquilvent SL	28,194	950,324	1.79	60.20
	8	Guzman Energia SL	26,637	976,961	1.69	61.89
	9	Parque Eolico La Boga SL	24,195	1,001,157	1.53	63.42
		Rest of the companies	577,331	309,740,992	36.56	100,00
2017	1	Acciona Group	544,644	544,644	27.57	27.57
	2	EDP Group	364,518	909,162	18.45	46.02
	3	Naturgy Renovables SLU	121,934	1,031,096	6.17	52.20
	4	Molinos Del Ebro SA	56,097	1,087,193	2.84	55.04

(continued)

Table 8 (continued)

Year	Position	Company Name	th EUR	Cumulative values	%	Cumulative %
	5	Parque Eolico La Boga SL	49,679	1,136,873	2.51	57.55
	6	Viesgo Renovables SL	45,087	1,181,960	2.28	59.83
	7	CYL Energia Eolica SL	33,430	1,215,390	1.69	61.52
	8	Esquilvent SL	31,307	1,246,697	1.58	63.11
	9	Guzman Energia SL	29,498	1,276,195	1.49	64.60
		Rest of the companies	699,246	406,713,472	35.42	100,00
2018	1	Acciona Group	604,661	604,661	29.41	29.41
	2	EDP Group	354,888	959,549	17.26	46.68
	3	Naturgy Renovables SLU	139,547	1,099,096	6.79	53.46
	4	Molinos Del Ebro SA	52,369	1,151,465	2.55	56.01
	5	Parque Eolico La Boga SL	49,318	1,200,784	2.40	58.41
	6	Viesgo Renovables SL	46,249	1,247,033	2.25	60.66
	7	CYL Energia Eolica SL	33,069	1,280,102	1.61	62.27
	8	Esquilvent SL	30,326	1,310,428	1.48	63.74
	9	Guzman Energia SL	27,892	1,338,320	1.36	65.10
		Rest of the companies	717,485	443,484,050	34.89	100,00
2019	1	Acciona Group	614,720	614,720	28.22	28.22
	2	EDP Group	363,004	977,723	16.67	44.89
	3	Naturgy Renovables SLU	182,156	1,159,879	8.36	53.25
	4	Viesgo Renovables SL	51,518	1,211,397	2.37	55.61
	5	Parque Eolico La Boga SL	49,937	1,261,334	2.29	57.91
	6	Molinos Del Ebro SA	47,195	1,308,529	2.17	60.07
	7	CYL Energia Eolica SL	31,992	1,340,521	1.47	61.54

(continued)

Table 8 (continued)

Year	Position	Company Name	th EUR	Cumulative values	%	Cumulative %
	8	Esquilvent SL	30,482	1,371,003	1.40	62.94
	9	Guzman Energia SL	29,328	1,400,331	1.35	64.29
		Rest of the companies	777,883	545,409,483	35.70	100,00
2020	1	Acciona Group	533,824	533,824	25.38	25.38
	2	EDP Group	332,156	865,980	15.79	41.17
	3	Naturgy Renovables SLU	255,317	1,121,297	12.14	53.31
	4	Viesgo Renovables SL	49,161	1,170,458	2.34	55.65
	5	Parque Eolico La Boga SL	48,833	1,219,291	2.32	57.97
	6	Molinos Del Ebro SA	31,170	1,250,460	1.48	59.45
	7	Esquilvent SL	30,825	1,281,286	1.47	60.92
	8	CYL Energia Eolica SL	30,476	1,311,762	1.45	62.37
	9	Guzman Energia SL	27,559	1,339,321	1.31	63.68
		Rest of the companies	763,917	558,482,055	36.32	100,00

companies, dedicated to the wind sector, which are provided with cutting-edge technology to compete. This is the case of the companies that are part of the Acciona and EDP groups studied in our analysis (López and Cebrián 2021).

The above strategies have been effective for the large energy business groups in Spain. The Gini index, calculated by including the business groups, shows a considerably higher index than the Gini index for individual companies. Analyzing the values contained in Table 9, we can affirm that the Spanish wind energy sector is a highly concentrated market.

Table 9 Value of the Gini index calculated including the business groups of the Spanish wind energy sector, 2020–2015

Gini index	2015	2016	2017	2018	2019	2020
Value	0.83	0.82	0.83	0.83	0.84	0.84
Variation rate	–	–1.20%	1.22%	0.00%	1.20%	0.00%

6 Conclusions

The wind energy sector in Spain is a market in continuous evolution. This statement is based on the fact that, on the one hand, technological improvements have decreased the costs supported by the companies and, on the other hand, the institutional framework applied to this sector has been repeatedly modified. Despite the changes in the rules of governance, the resilience of the sector, for more than three decades, remains high and it has turned out to be the most important renewable technology, in terms of generation, in Spain.

The bonus system has been one of the main growth factors in this sector. From 1998 until 2013, when state subsidies were legally cancelled, the industry was immersed in a continuous growth, but with a decreasing rate. The lack of available spaces to build a wind farm, together with the decrease in the power offered by the authorities, decreased the growth rates of the sector. Despite this, the expansion rate of the industry exceeded double-digit growth until 2010.

If the cancellation of the feed-in tariff system was the variable that caused the stagnation of the sector from 2013 onwards, the installation of the power awarded in the auctions, in 2019 and 2020, had the opposite effect. The year-on-year growth rates, for these last two years, did not reach the figures presented at the beginning of the twenty-first century, but show a positive evolution of the sector. This new resurgence of wind energy has large energy companies as its main players. These companies have followed a policy of purchasing, whereby they have become the holding company of other small and medium-sized companies in the market.

The acquired companies retain their corporate identity, but their management is transferred to the holding company. A characteristic feature shared by the investees is that they are companies with a good performance in the market and some of them even have a high degree of technification. The strategy of large companies is to improve the competitiveness of investees by providing them with better technology to reduce costs.

The concentration analysis carried out in this study shows that the large energy companies dominate the sector. Their market share and their position in it is consolidated, only Naturgy Renovables S.L.U. varies its position in 2020 after the installation of the power acquired in the auctions of 2016 and 2017. The results of the Gini index confirm the lack of competitiveness of the sector.

When the level of concentration is analyzed in terms of the groups of large companies, their percentage of market share is even higher. In this scenario, there is no competitive transition towards a new energy model. On the contrary, the dominant position of the large companies, previously leaders in fossil fuels and now leaders in renewable energy, is perpetuated.

There is an efficiency problem in the sector. This situation resulted from the state regulations for the allocation of energy capacity through auctions. The rules contemplate that the winners of the auction will be those who offer the lowest price for a wind project. Thus, the criteria for power allocation is not focused on efficiency. As a consequence, a large part of the wind power capacity has been allocated to the large energy companies, either to the parent company or to the investee companies. Moreover, as the legal framework for the promotion of renewable energy in Spain created a system of production premiums, these companies benefited from a significant transfer of public resources which, considering all renewable energies, amounted to 9 billion euros. The fact of receiving public premiums consolidated even more the position of these companies in the market. Therefore, we can affirm that the institutional framework itself indirectly favors the lack of competition in the market.

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Assessment of Electricity Market Liberalization in CEE Economies: A Multicriteria Approach

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Abstract Modern societies are becoming increasingly reliant on stable and secure energy sources to enable economic development. Electricity is inherently tied to economic growth and development, as it is a key determinant of the size and progress of an economy. Electricity markets in CEE economies have been liberalized and deregulated, and these processes are still ongoing. The primary goal of this study is to examine the liberalization and deregulation of the electricity markets in eleven Central and Eastern European EU Member Countries. The PROMETHEE II and Entropy methods are used to analyze five indicators (number of producers, cumulative market share generation, cumulative market share capacity, retailers to final consumers, and cumulative market share in the eleven countries (Bulgaria, The Czech Republic, Estonia, Croatia, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia, and The Slovak Republic), and the results are compared between 2007 and 2019, allowing for an assessment of overall changes in the electricity markets. The results show that Poland performed best in both analyzed years, while the Czech Republic maintained its second place. Further examination of the structure of CEE electricity markets indicated that supply and demand conditions remain notably different across the majority of the observed countries, signaling that more effort is necessary to integrate these markets into the single EU power market.

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1 Introduction

One of the major issues economies are facing today is increasing the availability of energy to fulfill the growing industry and transport demands without incurring unacceptable social, economic, and environmental consequences. With some caution, it can be argued that the economy has become the cause of poor or average environmental management because most pollutants are produced as a direct result of production and other anthropogenic activities (Mitić et al. 2020). According to Kojić et al. (2021), the majority of experts agree that anthropogenic pollution is the primary cause of environmental problems, with industry, energy, transportation, and agriculture being the most environmentally damaging sectors. Be that as it may, to support economic progress and prosperity, modern societies are growing increasingly reliant on reliable and secure energy sources. We can claim that electricity is inextricably linked to economic growth and development, as electricity production and consumption are some of the essential determinants of an economy's size and overall progress. Kamiński (2012) acknowledges this claim, stating that the electricity sector is one of the key sectors for any economy, as it is prone to be highly concentrated because of the high capital needs, entry barriers for new competitors, transmission constraints, and limited possibility of electricity storage.

The European energy market was tightly regulated in the 1990s to ensure energy security. Energy suppliers did not diversify their energy sources and were generally considered inefficient. The Single European Act, signed in 1986, aimed, among other things, to improve energy supply reliability, standardize energy pricing across Europe, and establish an internal energy market by 2014. However, when it comes to deliberating about European electricity markets liberalization, the year 1996 is a good place to start because the main goals since then have been to separate distribution from production, to make access to the distribution system easier, and to give consumers the right to choose their suppliers. Liberalization of the European electricity markets implied large mergers and acquisitions because the national producers needed foreign managerial expertise, access to the distribution channels, and improvement of their cost efficiency (Monastyrenko 2017). At present, all the electricity markets can be formally considered fully opened retail markets, but the reform of the electricity markets did not achieve the expected outcomes, because many European electricity markets still display oligopolistic features (Kamiński 2012).

The integration of the European energy market also increases the liberalization of the European electricity markets, implying better connectivity and technical arrangements on the electricity market (Jamasb and Pollitt 2005). Full integration of electricity markets implies significant efforts in the field of market concentration, investments, supply reliability, and market framework or regulation. Better connectivity between the national European markets means a convergence of the electricity price levels. To achieve the convergence there is a need for full integration of the European electricity markets that will lead to harmonization of electricity market legislation and market design, coordination of production infrastructures, and efficient and effective exploitation of resources (Castagneto-Gissey et al. 2014; Mastropietro et al. 2015). Although reforms have started, it should be noted that this is a long-lasting process. The challenges for the market integration are represented by structural market distortions, such as a low level of liberalization of certain European electricity markets, including regulated prices (kept at low levels to ensure access for all the consumers), and excessive market concentration for electricity production on some European Union markets. Opening markets and strengthening cross-border trading in the electricity field promoted by the European legislation should ultimately lower electricity prices and enhance competition (Castagneto-Gissey et al. 2014).

The number of main electricity suppliers has not constantly increased in the past decade in the EU. The number of suppliers diminished during 2010–2012 and then began to increase again. New energy supplier entries are difficult to maintain in the long term because this requires production liberalization. The electricity market proved to be less dynamic than expected and direct regulatory interventions remain essential for small or residential customers' welfare because of the market imperfections (Concettini and Creti 2013). However, end-consumers can freely choose their energy suppliers (Tolis et al. 2010) and they can freely change the suppliers. This trend of changing the retailer is more significant for large or small-sized consumers and less pronounced for small industries or households. For example, Ireland and Nordic countries are the most dynamic ones, followed by France, Germany, and Italy. Many EU countries removed regulated prices for end-users, and some of them only for non-residential consumers. Households and industries prefer regulated prices in countries where they still exist (Concettini and Creti 2013). Even though some new companies are operating as distributors and/or producers in the electricity markets, supply in many European countries remains concentrated at a few large companies.

The fact remains that the European Union has long expressed a desire for increased liberalization and has always been eager to build a single internal electricity market. All of this culminated in the adoption of various Directives, including 96/92/EC, 2003/54/EC, and 2009/72/EC, which had a considerable impact on the operation of the European power sectors (Kamiński 2012; Pollitt 2019). According to Kamiński (2012), market reforms in some countries focused primarily on unbundling, introducing competition in specific sub-sectors, and assuring non-discriminatory access to transmission and distribution networks. These reforms were sometimes accompanied by partial privatizations.

Nowadays, the EU tends to change its energy policy framework to assist in the transition away from fossil fuels and toward sustainable energy sources. This is following the EU's commitments to reduce greenhouse gas emissions under the Paris Agreement. All of this is covered under the Clean Energy for All Europeans package, whose rules should produce great benefits to the consumers, the environment, and the economy. The Package emphasizes the aim to combat global warming by coordinating these reforms at the EU level, and it contributes significantly to the

EU's long-term aim of achieving carbon neutrality by 2050 (European Commission 2021a). The Clean Energy for All Europeans package further aims to develop a modern design for Europe's electrical market, one that is more flexible, more market-based, and better positioned to integrate a higher share of renewables, among other things (European Commission 2021a). Accordingly, on the 1st of January 2020, the new Electricity Regulation—EU/2019/943 went into effect, outlining the essential principles for an efficient electricity market. It enables stronger national market integration and increased cross-border trading capacity, resulting in lower pricing. It also gives consumers more leverage and a head start on the energy transition by allowing more access to renewable energies and assuring better responsiveness to demand and storage (European Commission 2020). By 2030, for example, renewable energy sources are predicted to account for more than half of all electricity generated. But to address the needs of renewable energies, markets must be strengthened (European Commission 2021b). The legislation further includes regulations for improved coordination and collaboration amongst transmission system operators, enhancing electricity supply security, and it eliminates state subsidy that encourages a new generation of polluting electricity, resulting in tangible progress toward decarbonization. (European Commission 2020).

The main objective of this study is to analyze the electricity market liberalization and deregulation for selected Central and Eastern European (EU member) countries. To the best of our knowledge, there are no previous studies that used PROMETHEE II and Entropy methods for analyzing the selected set of eleven EU Central and Eastern European countries (Bulgaria, The Czech Republic, Estonia, Croatia, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia, and The Slovak Republic) and comparing the results between 2007 and 2019. This study aims to answer an important question as to how did the electricity market liberalization evolve during the 13 years, by investigating five indicators: (i) Producers, (ii) Cumulative Market Share Generation-Main Entities, (iii) Cumulative Market Share Capacity—Main Entities, (iv) Retailers to Final Consumers, and (v) Cumulative Market Share-Main Retailers.

The countries selected for this study were all previously organized as centrally planned economies that underwent extensive macroeconomic and structural reforms aimed at achieving robust growth. All countries have reaped significant benefits from EU membership in terms of unique opportunities coming from the trade-induced competition, pressures for policy reform, and increased financial integration. According to Schadler et al. (2006), growth in most Central and Eastern European countries has been significantly higher than the average for emerging market countries since 1996. However, assessing the performance of the countries of Central and Eastern Europe is convoluted by three intertwined phenomena. "Recovery from the immediate post-central-planning drop in output; the emergence of policies and institutional conditions (including EU membership) that enhanced catch-up potential; and global economic developments favorable to investment and growth in emerging market countries" (Schadler et al. 2006, pp.1). Nevertheless, the admission of Central and Eastern European countries to the EU resulted in an unbalanced Single Market, necessitating a review of Eastern members' positions and objectives in terms of economic, social, and energy sustainability (Andor 2019). Transitioning from a centrally planned to a market-based economy has resulted in significant structural changes in transitional economies, which even continue to impact the amount of regional CO_2 emissions (Mitić et al. 2017). Therefore, this study will attempt to answer the question of how did the electricity market liberalization evolve during the 13 years, and what is the current situation in the selected electricity markets in terms of liberalization.

The remainder of this paper is organized as follows. After the introduction section, a brief overview of the existing literature that explored trends and dynamics of electricity markets is presented in Sect. 2. Section 3 presents the development of key indicators relating to electricity markets in CEE economies, in order to gain an early understanding of the dynamic of reforms implemented throughout the observed period. Section 4 presents the data and methodology used for a comparative analysis of the liberalization of CEE electricity markets. Section 5 contains the results and discussion, whereas Sect. 6 is devoted to conclusions.

2 Literature Review

This section provides an overview of the literature related to the liberalization of electricity markets. Because of the size of the literature pool, we are mainly, but not exclusively, focusing on research that explores European countries. Due to the sheer number of existing literature, we are only able to provide a cursory review of the studies.

Since the early 1990s, Europe has been contemplating how to create a unified and competitive energy market. The EU has recognized a shared commitment for developing a strategic policy, aimed at achieving a fully competitive, unified European electricity and gas market, which will be open to competition amongst companies across Europe. Despite physical, economic, and political obstacles, the number of financial participants engaging in these markets is steadily expanding, and the markets' efficiency has improved significantly. The European energy markets, on the other hand, are a long way from the unique energy market objective. (Karan and Kazdağli 2011). In their studies, some authors, such as Joskow (2008), questioned whether governments had enough political will to make the necessary reforms in the electricity market to improve competition and if they can withstand pressures from interest groups. We are witnessing significant progress in terms of political will to improve the situation on European electricity markets, but it should be noted that there is a significant gap between declaratory political support and the adoption of directives and the actual situation on the markets.

In the context of electricity market reforms, Kaller et al. (2018) examined the impact of regulatory quality and non-compliance with the law on electricity prices. They concluded that boosting regulatory quality and lowering corruption have negative effects on prices. When these reforms are implemented in an institutional framework characterized by high levels of corruption and low-quality regulation, the intensity of the reforms has a limited influence on electricity pricing. Poudineh (2019) observed that retail electricity market liberalization was unable to keep up with technological advancement, consumer needs, and the energy transition. Reduced entry barriers in this sector have distorted competition, put consumers at risk, and resulted in an unequal allocation of system and public policy costs. One of the retail power markets' primary flaws has been a lack of consumer engagement.

There are studies like Matuszak and Kabaciński (2021), which considered the financial performance of state-owned companies in relation to non-commercial objectives. They demonstrate that while operating in lower-priced markets, state-owned companies underperform their privately-owned counterparts. This shows that pursuing goals other than profit maximization is likely to have a significant impact on their profitability.

Pollitt (2019) evaluated the broader evidence of the single market's impact on pricing, supply security, the environment, and innovation to assess the benefits of the single market. Although there have been major institutional reforms and market harmonization and integration, the quantifiable advantages are difficult to establish and are likely to be minor. This is largely due to a substantial increase in subsidized renewables over the same period. This is fully in line with other authors, such as Nicolli and Vona (2019) and Murshed (2020), who demonstrated in their studies that energy market liberalization enhances renewable energy consumption. Furthermore, Fiorio and Florio (2011) proved that discontent with private property in the electrical sector in Europe explains the continued importance of public ownership and the presence of residential price restrictions in many European nations. According to Foster et al. (2017), practically all developed countries and three-quarters of developing countries have enacted legislation to promote competition in the retail electricity market.

Central and Eastern European markets mainly display regulated electricity retail prices. According to Jankauskas (2014), the countries in the CEE region chose various approaches to unbundling electricity and gas providers. Because of the existence of a single (or dominant) supplier, which in many cases owned some shares in national companies, governments in the CEE region were unable to choose a more stringent option. CEE countries, and SEE for that matter, were of particular interest to other authors as well. For example, Vlahinić and Galović (2007) investigated whether regulatory reforms and a more liberalized environment would result in more cost-reflective prices and higher service quality. They find that, because of cost-reflective tariffs and the gradual phase-out of direct and indirect electricity price subsidies, most new EU Member States have seen a significant increase in electricity prices. Though cost-based tariffs have improved efficiency, they have impacted social welfare and competitiveness in CEE. On the other hand, the majority of SEE countries have low collection rates and continue to maintain low tariffs that do not reflect supplier costs. The attractions, obstacles, and challenges of Europeanisation in the SEE electricity sector were also a topic of investigation for Deitz et al. (2009), who considered whether the EU energy model is suitable in southeast Europe. The EU model provides certain institutional resources while also imposing major costs of compliance with the acquis's energy chapter. According to the analysis, regulatory reform may not be enough for several countries in the SEE region.

According to Gencer et al. (2020), failing to account for individual country characteristics could lead to a mismatch between markets and legislation, resulting in failure and the need for change. As a result, it's worth noting that one section of the vast literature pool focuses on particular countries rather than groups. In the context of our research, we will only mention a few studies that are pertinent to the countries of the CEE region. Poland, for example, has attracted a lot of attention in terms of its electrical markets (Kamiński and KudeŁko 2010; Kamiński 2012). Other countries do not lack research interest and have also been the subject of electricity markets research at one point, such as Slovakia (Sviteková et al. 2014; Janda 2018), Czech Republik (Vrba et al. 2015), Slovenia (Hrovatin et al. 2009; Papler and Bojnec 2012), Croatia (Fekete et al. 2009; Beus et al. 2018), Latvia (Bariss et al. 2017), Estonia (Vihalemm and Keller 2016), Lithuania (Streimikiene and Cibinskiene 2015), Romania (Maxim 2013, 2015), Bulgaria (Nedev 2015), and Hungary (Herczeg and Vastag 2019; Szőke et al. 2019, 2021).

3 Developments in the CEE Electricity Markets During 2007–2019

Electricity markets in CEE countries have been deregulated in recent decades. The goal was to reduce government control over the energy sector and to introduce competition into the previously monopolistic electricity market. To take an initial insight into trends of liberalization in the electricity markets in CEE countries during the 2007–2019 period, some key indicators should be analyzed. One of the important aspects of an electricity market is the number of producers indicating the situation on the supply side. In that sense, Table 1 presents the number of producers representing 95% of their total number in the CEE region in the observed period.

According to data presented in Table 1, it can be concluded that most of the observed countries had a low number of producers. Only Poland and Hungary had more producers than the CEE average. These countries, along with the advanced market economies used as a benchmark, demonstrate that the number of producers is not directly related to country size, but rather to the level of market deregulation. Poland had the highest average growth rate of this indicator, so the number of producers has increased over 4 times in 2019 in comparison to the beginning of the observed period. This expansion is largely due to the country's commitment to diversify its energy mix in favor of renewable energy sources (Paska et al. 2020). Hungary experienced a sharp drop in the number of producers in 2012, and after years of fluctuation, this indicator increased in 2019. The number of producers grew when the third electricity law went into effect in 2008, cutting the regulatory barriers to entry into the market. Hungary formed a new government in 2010. Even though the new government did not change the regulatory framework, it planned to increase national ownership in the supply chain while lowering residential electricity prices. Following that, the declining profitability of electricity production and the growing

Table 1 Producers, Representing 95% Total (number)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bulgaria	15	15	15	22	20	28	83	55	75	79	113	133	159
Czech Republic	16	16	19	24	51	73	21	45	150	220	230	278	315
Estonia	2	2	5	6	6	5	8	10	11	11	9	9	12
Croatia	2	2	2	2	2	2	2	3	6	7	12	16	24
Latvia	8	8	10	11	17	17	43	76	80	84	96	72	67
Lithuania	7	7	8	9	10	17	20	20	23	27	25	25	26
Hungary	61	52	69	68	68	32	45	39	39	26	30	39	71
Poland	54	55	59	68	73	111	103	128	162	197	211	202	241
Romania	18	15	10	10	10	11	15	27	29	29	32	27	29
Slovenia	3	2	2	3	3	3	3	3	3	3	3	3	4
Slovak Republic	7	6	7	8	9	11	10	17	21	22	22	23	24
CEE average	18	16	19	21	24	28	32	38	54	64	71	75	88
Austria	106	137	128	126	129	145	169	201	192	226	228	226	248
Netherlands	1000	1000	900	700	700	800	700	350	650	300	350	350	350

Source Eurostat (2021)

importance of traders increased traders' market power, resulting in a fall in the number of producers (Szőke et al. 2019).

The number of producers in Romania was comparable to the CEE average in 2007. Romania had the number of producers equal to the CEE average. Romania's electricity market liberalization began after 2000. Although Romania was not yet a member of the European Union at the time, it began to develop a functioning electricity market by efficiently restructuring the energy sector (Maxim and Cărare 2014). This country created a favorable legislative framework.

When Romania joined the European Union in 2007, the process of liberalization of the Romanian electricity market was completed. Despite the creation of a favorable legislative framework to attract FDI in this sector (Haar and Marinescu 2011), the pace of liberalization slowed slightly due to inefficient implementation of deregulation measures, resulting in a relatively low number of producers in 2019 in comparison to Bulgaria, which joined the EU the same year. Bulgaria experienced impressive growth in the number of producers, with only Poland and the Czech Republic having a higher value of this indicator in 2019. In 2015, the Bulgarian Energy Act was amended, resulting in a substantial increase in the number of producers due to the establishment of national regulatory body independence and the establishment of a new Energy System Security Fund. The fact that Bulgaria's energy market is divided into a regulated and a liberalized section indicates that there is still room for progress in this area (OECD 2019).

It is interesting to note that only Bulgaria and Croatia recorded continuous growth in the numbers of producers during the period. Croatia, along with Estonia, was the country with the lowest number of producers. But, during the time, Croatia experienced faster growth of this indicator than Estonia. The ownership unbundling of state-owned enterprises in Croatia has been delayed for a long time (Beus et al. 2018), but after EU accession the accelerated growth of this indicator started, resulting in a twice higher number of producers than in Estonia at the end of the considered period. The rise in the number of producers in Estonia has been hampered by the dominant position of one large energy firm.

The highest growth of this indicator is recorded in the Czech Republic. During the observed period, the number of producers increased nearly 20 times, resulting in nearly 300 new competitors in the electricity market of this country in 2019. On the other hand, Slovenia is the country that made the least progress in this regard during the considered period and ended up as the country with the lowest number of producers among CEE economies.

In the end, it should be emphasized that only Bulgaria, Poland, and the Czech Republic had higher than the CEE average value of this indicator in 2019, and the Czech Republic outperformed Austria as a benchmarking market economy in this regard.

Another important indicator of electricity markets is the cumulative market shares in terms of electricity generation for the main producers, which is presented in Table 2.

Table 2 Cumulative market share generation, main entities (%)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bulgaria	76	80	71	73	82	76	75	74	78	78	77	78	60
Czech Republic	74	73	74	73	69	68	65	64	62	60	68	68	61
Estonia	94	97	90	89	87	88	87	85	80	81	83	80	76
Croatia	96	98	99	99	98	97	95	92	90	96	86	83	80
Latvia	92	93	87	88	86	89	80	80	57	59	47	63	86
Lithuania	87	88	82	82	75	75	69	66	63	49	41	39	54
Hungary	79	84	66	66	61	70	71	74	72	76	79	80	56
Poland	44	46	45	44	43	37	37	37	25	30	30	33	28
Romania	86	89	85	89	91	69	76	68	65	66	63	77	54
Slovenia	94	97	95	95	95	94	95	93	92	94	92	96	87
Slovak Republic	83	84	82	81	78	79	84	82	73	71	71	78	69
CEE average	82	84	80	80	79	76	76	74	69	69	67	70	65
Austria	52	51	56	56	55	57	56	55	53	52	51	52	54
Netherlands	62	59	59	60	58	55	58	60	62	56	52	49	50

Source Eurostat (2021)

According to the data in Table 2, this indicator has experienced considerable variations in all CEE economies during the period. However, in comparison to 2007, all considered economies recorded the decline in this share in 2019.

Comparing the data for the CEE countries with the CEE average, it can be noticed that Poland had the lowest share during the entire observed period and it was even lower in comparison to the CEE average and benchmarking countries. All remaining countries started the observed period with a significantly higher value of this indicator. After a period of divergent changes, the differences among CEE economies regarding this indicator were much higher in 2019. Lithuania, Hungary, and Romania had also a relatively low value of this indicator in 2019. In Lithuania and Romania, it was like in Austria, as a benchmarking country, while in Hungary it was slightly higher.

Bulgaria, the Czech Republic, and the Slovak Republic displayed in 2019 a cumulative market share close to the CEE average, but only Slovak Republic started in 2007 with the same share as the CEE average, while Bulgaria and the Czech Republic started in 2007 from lower cumulative market shares comparing to the CEE average. In Bulgaria, the public sector holds a major share of energy generation, limiting the growth of open-price competition and boosting the sector's overall efficiency (EBRD 2015).

Estonia, Croatia, Latvia, and Slovenia had the highest values of this indicator at the beginning of the study period and ended the observation period with a high value of this share (considerably above the CEE average). It is worth noting that Latvia experienced a large drop in this indicator in 2015, and it remained below the CEE average value until 2019 when it rapidly rose.

Besides the cumulative share of main producers in total electricity generation, a very important aspect of market liberalization is also their cumulative share in total capacity. The data on this indicator is presented in Table 3.

According to the data in Table 3, Poland had the lowest share of main producers in total capacity over the entire considered period, which was lower than the CEE average and value of this indicator in benchmarking advanced EU economies. Slovenia, on the other hand, had a greater than 90% share of main entities in total capacity during the entire period. This country, along with Croatia, exceeds the CEE average for this indicator. Croatia and Latvia initially had exceptionally high values for this indicator but improved their situation until the end of the observation period. This is especially true for Latvia, where the value of this indicator was lower at the end of the period than the CEE average.

It is worth noting that Bulgaria witnessed the greatest increase in the cumulative share of main entities in total capacity. It was more than doubled in 2019 compared to 2007, indicating an intense concentration of capacities among major entities. Apart from Bulgaria, only the Czech Republic and Hungary experienced a rise in this share in 2019 compared to the start of the observation period. All remaining nations saw a reduction in this share, with Lithuania implementing the most extensive deregulation. It almost halved this share at the end of the period in contrast to 2007. Aside from Lithuania, Estonia, Croatia, and Latvia substantially reduced the cumulative proportion of major entities in total capacity, while other CEE economies slightly reduced

Table 3 Cumulative market share capacity, main entities (%)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bulgaria	38	52	51	58	82	59	57	63	73	74	73	63	78
Czech Republic	69	69	71	85	58	57	53	51	49	50	61	60	75
Estonia	87	92	83	82	80	77	77	76	72	70	72	74	67
Croatia	98	98	99	98	97	95	93	91	85	83	82	82	78
Latvia	95	92	93	92	92	90	90	55	87	86	85	86	67
Lithuania	75	71	78	83	77	86	77	75	67	50	55	54	39
Hungary	76	71	62	50	70	60	35	62	61	63	49	65	77
Poland	36	42	32	26	25	24	19	19	19	18	20	20	35
Romania	77	82	81	68	73	55	57	56	58	57	57	51	72
Slovenia	95	96	96	94	94	94	94	87	93	94	93	94	92
Slovak Republic	82	83	79	71	72	72	58	67	56	73	74	71	80
CEE average	75	77	75	73	75	70	64	64	65	65	66	66	69
Austria	50	70	68	57	59	58	56	61	60	58	58	58	53
Netherlands	59	57	54	59	53	55	56	58	57	52	52	60	52

Source Eurostat (2021)

this share and maintained the share at almost the same level as at the beginning of the period.

Aside from analyzing developments in the manufacturing sector, it is critical to examine improvements in the retail electricity market. Deregulation in this sector affects energy prices and, more broadly, consumer well-being. The separation of electricity production from distribution and retailing, as well as the ability for customers to choose retailers, played a key role in the deregulation process. In this regard, Table 4 shows the retailer-to-final-consumer ratio.

From the first glance at Table 4, it is clear that Poland and the Czech Republic considerably outperformed the CEE average throughout the whole period. The Czech Republic even exceeded both benchmarking advanced economies in this regard. Countries that have made also visible improvement are Romania and Slovak Republic. Romania even exceeded the CEE average since 2014.

It is worth noting that Bulgaria witnessed tremendous development over the period, with the value of this ratio increasing by about 7 times in 2019 in comparison to 2007. However, because of its poor starting position, it continues to lag behind the majority of CEE economies. Croatia, Latvia, and Lithuania likewise have a low starting point. In contrast to Croatia, which had made the fewest efforts among CEE countries to improve the condition of affairs in this area, the remaining two countries had made some progress. In January 2015, the Latvian retail market for electricity became fully liberalized, which increased the level of competition in this market (EBRD 2015). Lithuanian retail energy market was gradually liberalized from 2013,

Table 4 Retailers to final consumers (number)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bulgaria	7	7	17	36	45	24	24	29	37	54	57	53	48
Czech Republic	293	281	281	324	356	360	382	380	390	389	399	411	409
Estonia	40	37	40	41	40	42	49	53	46	49	46	45	50
Croatia	2	2	2	3	7	9	6	7	7	7	9	9	8
Latvia	6	4	4	4	5	6	8	12	17	21	26	25	22
Lithuania	7	8	9	15	27	27	24	23	17	21	22	21	22
Hungary	17	24	35	38	39	43	44	51	52	42	42	39	37
Poland	158	137	150	146	135	134	145	140	134	134	190	185	208
Romania	51	48	47	56	61	54	60	86	95	105	105	96	91
Slovenia	14	14	17	16	16	13	14	13	18	20	21	23	22
Slovak Republic	36	47	67	77	68	71	60	66	72	74	71	73	68
CEE average	57	55	61	69	73	71	74	78	80	83	90	89	90
Austria	160	141	>140	129	155	152	154	149	155	162	171	171	174
Netherlands	39	38	32	36	35	35	45	46	51	53	48	48	52

Source Eurostat (2021)

by promotion of competition and choice for retail electricity consumers (International Energy Agency 2021) The implementation of mentioned measures in Latvia and Lithuania raised this ratio over three times in 2019 compared to 2007, and these countries approached Slovenia in this regard, which had a slightly better starting position. Slovenian customers have benefited from increased competition and enabled retailer choice, resulting from gradual market deregulation and price liberalization in the electricity retail market. This market has been fully liberalized in 2007 (Bojnec & Križaj 2021). Finally, it should be highlighted that all of the other countries studied have only achieved minor progress in this area.

The number of retailers per consumer is only one component of the energy retailing market. Another crucial factor is the cumulative share of major retailers in overall market share, as seen in Table 5.

According to Table 5, the majority of the CEE economies studied experienced a drop in this percentage. Bulgaria has had the greatest drop, having cut its share from 2007 by one-third in 2019. The Czech Republic experienced a somewhat lesser decline than Bulgaria, but due to a lower starting position, this country outperformed Bulgaria in 2019. This country finished the period with the lowest value of this indicator, which is even lower than the CEE average and those reported in advanced market economies used for benchmarking. Croatia and Latvia have very high values of this indicator (greater than the CEE average) and, as a result, considerable concentration in this market till 2015. After that, both countries achieved minor improvement, but Croatia witnessed a rapid increase in this indicator, which was the

Table 5 Cumulative market share, main retailers (%)

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bulgaria	99.8	98.4	93.3	84.6	61.5	92.5	83.0	81.1	76.7	64.8	69.6	63.5	67.2
Czech Republic	86.9	84.0	88.2	87.9	84.6	69.2	70.2	67.8	67.5	66.1	86.9	83.4	59.1
Estonia	99.0	87.7	87.0	73.0	78.6	81.6	73.9	78.4	70.3	68.4	71.7	76.1	84.0
Croatia	100	100	100	100	98.0	95.0	96.0	93.9	92.3	86.0	89.0	88.1	95.7
Latvia	100	100	100	99.9	99.9	99.8	96.1	100	93.9	90.2	82.4	81.9	80.7
Lithuania	91.0	91.9	92.8	87.1	84.8	96.0	89.9	96.7	91.7	88.9	93.2	95.7	93.7
Hungary	87.3	89.5	76.0	78.0	82.7	67.9	76.1	73.5	70.4	96.1	76.1	71.2	76.7
Poland	63.5	69.4	72.6	70.3	73.7	79.9	83.4	78.9	85.1	78.4	78.3	77.0	76.3
Romania	77.4	67.3	70.1	66.8	66.9	66.4	65.0	62.3	61.2	60.7	63.0	55.0	61.5
Slovenia	94.0	99.0	98.0	99.0	97.2	96.4	94.9	98.5	93.9	94.1	89.8	93.1	92.3
Slovak Republic	86.4	86.5	86.4	86.4	86.3	81.9	82.1	83.3	70.1	75.0	76.0	75.5	78.6
CEE average	89.6	88.5	87.7	84.8	83.1	84.2	82.8	83.1	79.4	79.0	79.6	78.2	78.7
Austria	82.0	87.5	87.0	92.0	62.0	85.0	79.0	80.0	82.0	77.0	76.0	76.0	76.0
Netherlands	88.0	87.0	85.0	75.0	74.0	74.0	76.0	70.0	72.0	73.0	71.0	68.0	78.0

Source Eurostat (2021)

highest among CEE economies in 2019. Some modest improvements were recorded in Latvia, Romania, and Estonia, however, due to a low starting position, Romania recorded a value below the average for this indicator.

On the other hand, Poland and Lithuania are economies that have recorded growth of this indicator in 2019 in comparison to 2007. Although an increase in Poland was greater, this country recorded near to the average value of this indicator in 2019, due to better initial conditions. Lithuania, however, had over the average value of this indicator during the entire observed period except in 2016. Slovenia had above the CEE average value of this share, although a minor decrease was recorded. These countries face significant reforms to be implemented in the future.

4 Data and Methodology

In order to perform a comparative analysis of electricity sector reform in considered countries, the PROMETHEE method is applied in combination with the entropy method, which is used for weights calculation. The comparisons are performed by the ranking of analyzed CEE countries in 2007 (as first available data) and 2019 (as last available data). After that, the comparison of ranking results for observed years is done to identify differences in rankings, resulting from the different pace of reforms implementation.

4.1 The Data

The evaluation of energy sector reform requires analysis of different aspects of the electricity sector functioning, especially market liberalization. The assessment of electricity market reform is performed by considering five indicators:

1. Main Producers, Representing 95% Total (number)—P,
2. Cumulative Market Share Generation, Main Entities (%)—CMSG,
3. Cumulative Market Share Capacity, Main Entities (%)—CMSC,
4. Main Retailers to Final Consumers (number)—RFC,
5. Cumulative Market Share, Main Retailers (%)—CMSMR.

All considered indicators are downloaded from the Eurostat database—EU Energy Datasheets (Eurostat 2021).

4.2 Methodology

4.2.1 PROMETHEE II Method

To conduct an objective comparative analysis of electricity market reform in considered countries according to all five criteria together, an application of some of the multi-criteria decision methods (MCDM) is required. After detailed consideration of various MCDMs (Kumar et al. 2017), while keeping in mind the characteristics of the research problem, the PROMETHEE II method was selected, as one of the most commonly used multi-criteria methods. The decision on using this method was made based on its advantages. Ulengin et al. (2001) emphasizes the following advantages of this method: its user-friendly outranking method, its efficiency in application to real-life problems, and its ability to perform complete rankings of alternatives. An additional motive for the selection of the PROMETHEE II method is the availability of various graphical interpretations of obtained results (Živković et al. 2017). Due to numerous advantages, this method is frequently applied for multi-criteria analysis in various research areas (Antanasijević et al. 2017; Radulescu et al. 2017; Strantzali et al. 2017; Krstić and Fedajev 2020; Remeikienė et al. 2021; Schär and Geldermann 2021).

The first step in the usage of the PROMETHEE II method is the definition of the parameters of a decision-making problem, which includes defining the direction of preference, weight coefficient, preference function, and appropriate thresholds, depending on the selected preference function (Herngren et al. 2006; Behzadian et al. 2010). This method is grounded on a stepwise procedure that calculates the net preference flow (Phi) for each alternative determining its position in the final ranking. All observed alternatives are expressed in terms of preference level, which is derived by taking into account the differences between each pair of alternatives using each criterion separately. The bigger the disparity between alternatives in terms of some criteria, the more important that alternative is in regarding that criterion. The preference level is calculated by the application of the selected preference function and thresholds. It can assume values of 0 to 1 (Brans & De Smet 2016; Dachowski and Gałek 2020; Remeikienė et al. 2021). For example, when comparing alternative a with alternative b, alternative a is better than alternative b regarding specific criteria if the value of preference function for alternative a is higher than for alternative b. After that, for each alternative, the positive preference flow (Phi+) and negative preference flow (Phi+) are calculated and, based on the difference between them, Phi is calculated. At the very end, the considered alternatives are ranked based on Phi value. Phi takes values ranging from −1 to 1. The best-ranked alternative has the highest positive Phi value, while the worst-ranked alternative has the highest negative Phi value (Brans et al. 1984; Mladenović-Ranisavljević et al. 2012; Obradović et al. 2012).

4.2.2 Entropy Method

As previously stated, the PROMETHEE II method assumes that each considered criterion is given an appropriate weight, which represents the importance of that criterion in the final ranking of alternatives. There are many different ways to define weights, and they can be divided into three categories: subjective, objective, and integrated weighting methods (Odu 2019). Taking into account the research problem and data availability, the entropy method is employed for the calculation of weights. It decreases subjectivity during analysis and assigns relative importance to criteria based on differences between alternatives for each of the criteria. The entropy method calculates weights based on the information entropy of criteria. The creation of a decision matrix is the first step in using the entropy approach. In some circumstances, this matrix should be normalized, with the appropriate formula based on the direction of preference. The goal of normalization is to remove the difference of criteria in dimension and order of magnitude (Chen 2019; Remeikienė et al. 2021). After normalization, the information entropy is determined, which is then utilized to calculate the weights in the next phase. It is worth noting that criteria for which differences among alternatives are more pronounced, information entropy is lower and, as a result, weight coefficient is higher. Otherwise, the lower difference among alternatives in specific criteria is, the information entropy is lower and, consequently, the weight coefficient is lower. Another noteworthy feature of the calculated weight coefficients is that their sum amounts to 1 (Zou et al. 2006; Fedajev et al. 2021).

5 Ranking Results

The PROMETHEE II method is used to rank CEE economies based on the examined indicators to determine how they performed at the start of the observed period. Because this method implies the definition of weights, the entropy method was used, and the weights generated for 2007, as well as other multi-criteria analysis parameters, are shown in Table 6.

Table 6 Multi-criteria analysis parameters for 2007

Parameters	Indicators				
	P	CMSG	CMSC	RFC	CMSMR
Preference direction	Max	Min	Min	Max	Min
Weight	0.29	0.12	0.20	0.25	0.15
Preference function	V-shape	V-shape	V-shape	V-shape	V-shape
Threshold unit	Absolute	Absolute	Absolute	Absolute	Absolute
Preference threshold	19.62	14.07	20.12	85.67	10.67

Source Authors' calculations

Table 6 shows that the number of producers (P) and retailers per final consumer (RFC) should be maximized, while the other evaluated indicators should be minimized. It is worth noting that the number of producers (P) has the highest weight coefficient, indicating that this is where the most disparities between CEE economies are found. The number of retailers per final consumer (RFC) is given a little lower, but still, rather high weight, suggesting that the analyzed economies diverge significantly in this area as well. On the other hand, the cumulative market share of major producers in overall electricity generation (CMSG) has the lowest weight, indicating that the smallest variances across the investigated economies are recorded for this indicator. For all indicators, the V-shape preference function was selected, with absolute preference thresholds set at the standard deviation level. Such an approach is selected to obtain absolute dominance of better alternatives where the difference between two alternatives exceeds standard deviation as a measure of dispersion.

The Visual PROMETHEE software (Visual Decision Inc. Montreal, Canada-academic version) was used to rank EU countries based on defined parameters and an evaluation matrix (consisting of the database for 2007). The results are shown in Table 7.

According to the results shown in Table 7, Poland was the best-performing country across all criteria in 2007. Apart from Poland, the Czech Republic, Hungary, Romania, and Bulgaria all had a positive net preference flow, indicating that those countries had more advantages than constraints in terms of the indicators under consideration. The Slovak Republic, Lithuania, Estonia, Slovenia, Latvia, and Croatia were among the countries where constraints outweighed advantages, resulting in a negative preference flow.

Visual PROMETHEE software enables the creation of some helpful graphical representations. The so-called Rainbow diagram, as seen in Fig. 1, is one of them. This

Table 7 Rankings for 2007

Rank	Country	Phi	Phi +	Phi-
1	Poland	0.8943	0.9291	0.0348
2	Czech Republic	0.4726	0.6143	0.1418
3	Hungary	0.3285	0.4958	0.1673
4	Romania	0.2178	0.4295	0.2117
5	Bulgaria	0.0852	0.3445	0.2593
6	Slovak Republic	−0.0434	0.2375	0.2809
7	Lithuania	−0.1422	0.1792	0.3214
8	Estonia	−0.3698	0.0871	0.4569
9	Slovenia	−0.4332	0.0489	0.4822
10	Latvia	−0.4384	0.0388	0.4773
11	Croatia	−0.5711	0	0.5711

Source Authors' calculations

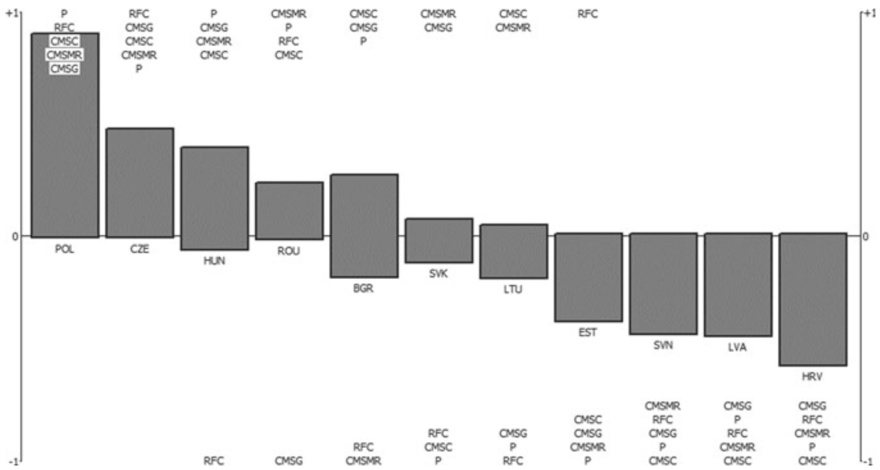

Fig. 1 Rainbow diagram for 2007. *Source* Authors' calculations

diagram is valuable since it shows the advantages and disadvantages of each alternative (in this case, countries). The advantages are displayed above the histograms, while the disadvantages are displayed below the histogram.

The top five ranked countries have more advantages than disadvantages, as shown in Fig. 1, resulting in their favorable position in the final rankings. It is interesting to note that two top-ranked countries have the same number of advantages.

The rankings were also conducted for 2019 to explore the dynamics of market liberalization in CEE economies during the studied period. The ranking process requires the definition of multi-criteria analysis parameters in 2019, which are shown in Table 8.

The first insight in Table 8 suggests that discrepancies across CEE economies have merely been reduced, given the fact that weights' differences were significantly less pronounced in 2019 than in 2007. It can be seen that again the differences in the number of producers are the most pronounced (highest weight is obtained for P), while the less pronounced differences are still in the cumulative market share of major

Table 8 Multi-criteria analysis parameters for 2019

Parameters	Indicators				
	P	CMSG	CMSC	RFC	CMSMR
Preference direction	Max	Min	Min	Max	Min
Weight	0.26	0.14	0.16	0.22	0.21
Preference function	V-shape	V-shape	V-shape	V-shape	V-shape
Threshold unit	Absolute	Absolute	Absolute	Absolute	Absolute
Preference threshold	99.57	16.57	16.47	113.99	11.90

Source Authors' calculations

producers in overall electricity generation (the lowest weight is obtained for CMSG). Also, it should be noted that differences in CMSC and RFC were slightly reduced, which is evidenced by lower weights for these indicators in 2019 in comparison to 2007, while differences in CMSMR were increased.

The same approach was carried out using the parameters and evaluation matrix for 2019, and the ranking results are shown in Table 9.

According to the data in Table 9, Poland and the Czech Republic have retained their positions in the final rankings from 2007. Bulgaria and Romania remained countries with positive net preference flow. Bulgaria improved its position moving from fifth to third position, while Romania retained the fourth position. Hungary, which was among the countries with positive preference flow in 2007, has slipped to the bottom of the rankings and has become a country with negative preference flow. In addition to Hungary, Lithuania, Latvia, the Slovak Republic, Estonia, Croatia, and Slovenia had disadvantages that outweighed advantages in 2019. When comparing these countries, it should be noted that Lithuania, Latvia, and Croatia improved their positions in 2019, whereas the Slovak Republic, Estonia, and Slovenia deteriorated. The first step in the analysis of these changes is the generation of a rainbow diagram from Visual PROMETHEE software for 2019. It is presented in Fig. 2.

According to Fig. 2, it can be concluded that Poland retained its first position due to retaining the advantage regarding all analyzed aspects of electricity market liberalization. Although it retained its position from the 2007 rankings, the Czech Republic has increased CMSC, which has become its disadvantage in 2019. On the other side, Croatia and Slovenia remained disadvantaged in all observed areas in 2019. However, Croatia slightly improved its position compared to 2007, while Slovenia deteriorated from the ninth position to the very bottom of the rankings. The more detailed overview of countries' characteristics in both analyzed years and

Table 9 Rankings for 2019

Rank	Country	Phi	Phi +	Phi-
1	Poland	0.7188	0.8183	0.0994
2	Czech Republic	0.6764	0.7586	0.0822
3	Bulgaria	0.2511	0.4711	0.2200
4	Romania	0.1977	0.4046	0.2069
5	Hungary	−0.0017	0.2779	0.2796
6	Lithuania	−0.1242	0.2446	0.3688
7	Latvia	−0.1688	0.2179	0.3866
8	Slovak Republic	−0.1775	0.1912	0.3687
9	Estonia	−0.2289	0.1764	0.4053
10	Croatia	−0.5116	0.0353	0.5469
11	Slovenia	−0.6315	0.0132	0.6447

Source Authors' calculations

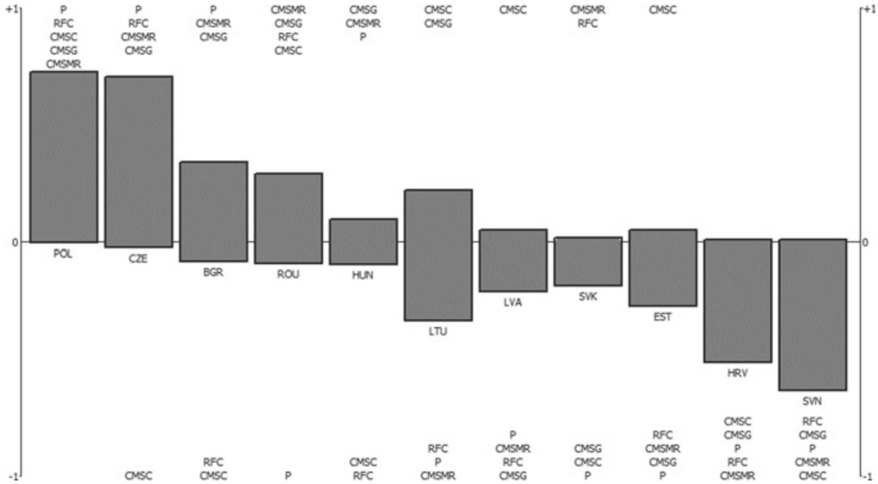

Fig. 2 Rainbow diagram for 2019. *Source* Authors' calculations

changes over time is enabled by the usage of another valuable graphical representation provided by Visual PROMETHEE software named alternatives' profiles, which are presented in the Appendix.

6 Conclusions

The European electricity market has experienced rapid economic and technological transformation during the last decade due to an increase in energy production from renewable sources combined with increasing dependency on electrical energy. The accelerated economic growth has caused electricity consumption to be one of the frontline topics, along with numerous economic and ecological issues. Such developments have raised concerns among certain stakeholders and governments about whether and how will the electricity demand be met in the future. CEE economies were particularly faced with these challenges, considering that liberalization and deregulation processes in electricity markets of these economies are still ongoing. This was the primary motivation for researching the electricity market liberalization in CEE economies. A comparison of findings from 2007 (the earliest available data) and 2019 (the most recent accessible data) allowed for an assessment of overall trends in the market for this strategic commodity.

According to the findings, Poland performed the best in both years studied, outperforming other countries in all assessed indicators, owing to its determination to reduce coal-fired electricity production by expanding the number of producers using alternative energy sources, particularly renewables. Even though the share of main producers in total capacities increased in comparison to 2007, and other countries made progress in this regard, the Czech Republic maintained its second place from 2007 ranking. It is worth noting that, in comparison to 2007 rankings, Hungary and Bulgaria switched places in the final 2019 rankings. Hungary lost its third position in the 2007 rankings to Bulgaria, because, in addition to the small number of retailers per consumer, the country's large share of major companies in electricity production capacity appeared to be a disadvantage. Slovenia is at the bottom of the 2019 rankings, with a disadvantage in all of the observed indicators when compared to the other countries. This country's performance has deteriorated since 2007, and it has now replaced Croatia as the bottom-ranked country. However, both countries have unfavorable values of the considered indicators and, as a result, a poor position in comparison to other countries due to a lack of competition in the electricity sector and a continued substantial share of state companies in the market.

An examination of the structure of CEE electricity markets reveals that supply and demand conditions remain notably different across the considered countries, emphasizing that more effort is needed to integrate these markets into the single EU electricity market. The gradual integration of the EU electricity market will be critical in overcoming the EU market's remaining fragmentation. Despite progress in liberalization, the leading producers' proportion of national production in many countries remains substantial. As a result, improving competition must remain a priority for national and EU energy policies, including the implementation of competition laws. Greater physical interconnection of energy networks, as well as more efficient electricity trading systems, such as market interconnection, can, to the benefit of consumers, at least partially replace alternative supply systems that are absent at the national level. Renewable energy has also made it easier for new competitors to enter the market, which has helped to reduce market concentration.

Data availability, or the lack thereof, is one of the study's major limitations. There is a lack of data for 2020, to assess the most recent status in this sector, as well as several years before 2007 when the majority of the countries studied joined the EU. Other indicators could be included in future studies to analyze their impact on electricity markets. When discussing future EU electricity markets, the influence of the COVID-19 epidemic and its ramifications on reforming and integrating electricity markets in the EU Member States should also be considered.

Appendix

Country Profiles.

See Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13.

POLAND

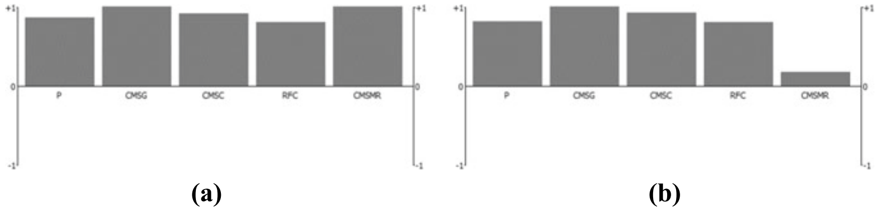

Fig. 3 **a** Profile of Poland in 2007, **b** Profile of Poland in 2019

THE CZECH REPUBLIC

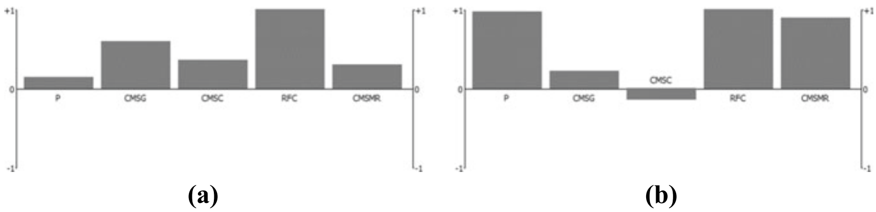

Fig. 4 **a** Profile of the Czech Republic in 2007, **b** Profile of the Czech Republic in 2019

BULGARIA

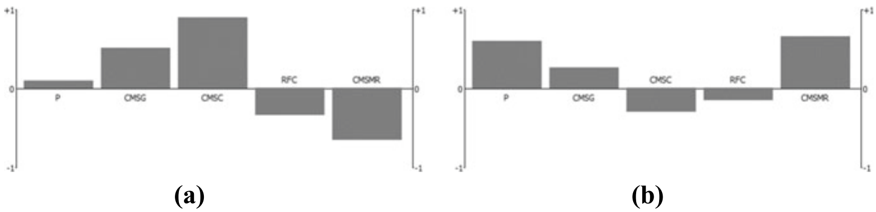

Fig. 5 **a** Profile of Bulgaria in 2007, **b** Profile of Bulgaria in 2019

ROMANIA

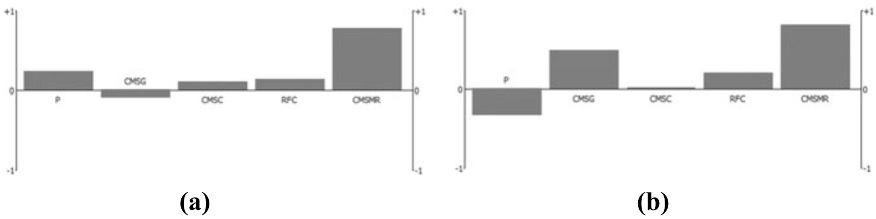

Fig. 6 **a** Profile of Romania in 2007, **b** Profile of Romania in 2019

HUNGARY

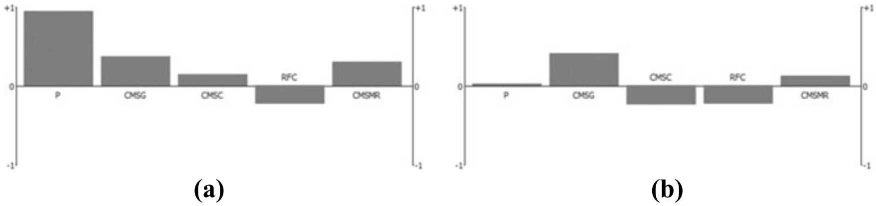

Fig. 7 **a** Profile of Hungary in 2007, **b** Profile of Hungary in 2019

LITHUANIA

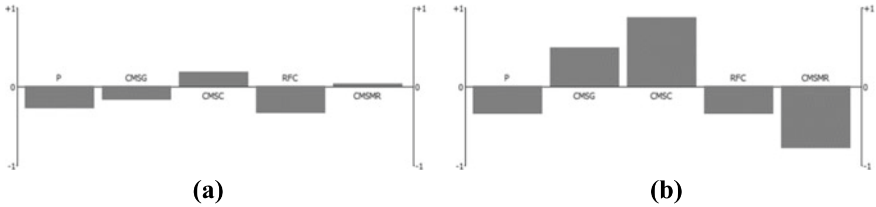

Fig. 8 **a** Profile of Lithuania in 2007, **b** Profile of Lithuania in 2019

LATVIA

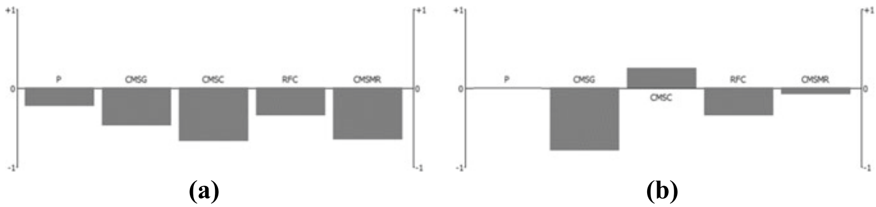

Fig. 9 **a** Profile of Latvia in 2007, **b** Profile of Latvia in 2019

THE SLOVAK REPUBLIC

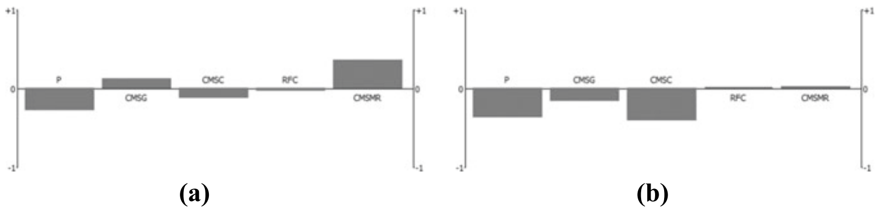

Fig. 10 **a** Profile of the Slovak Republic in 2007, **b** Profile of the Slovak Republic in 2019

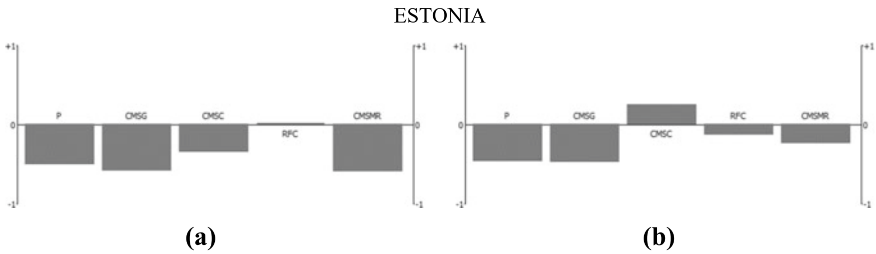

Fig. 11 **a** Profile of Estonia in 2007, **b** Profile of Estonia in 2019

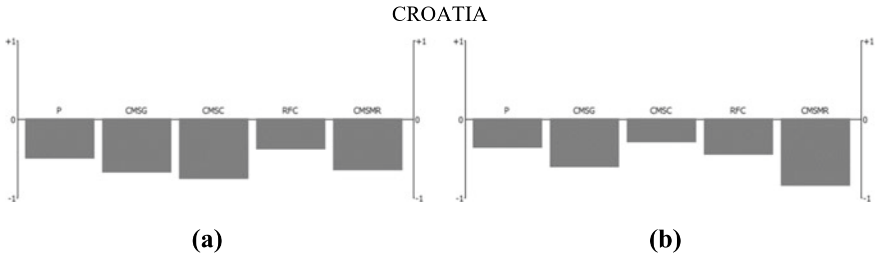

Fig. 12 **a** Profile of Croatia in 2007, **b** Profile of Croatia in 2019

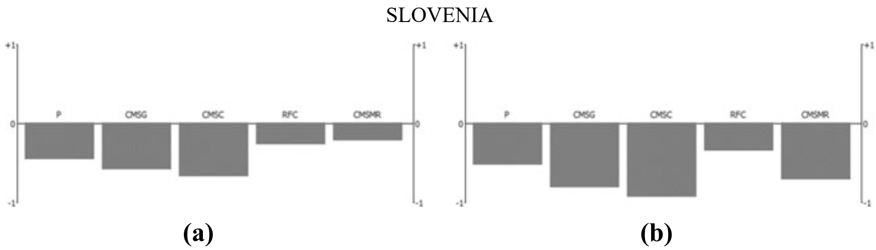

Fig. 13 **a** Profile of Slovenia in 2007, **b** Profile of Slovenia in 2019

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The Economic Impact of the Coronavirus Pandemic (COVID-2019): Implications for the Energy Sector

Fatbardha Morina, Katerina Lyroudi, and Chrysanthi Balomenou

Abstract This study investigates the impact of the coronavirus pandemic due to COVID-19 on the stock market outcomes for the leading energy companies that operate in Europe. We applied the Fixed Effects model to achieve our objectives. The final sample consisted of 39 companies from the following European countries: Austria, Denmark, Finland, France, Germany, Greece, Hungary, the Republic of Ireland, Italy, Luxemburg, Netherlands, Norway, Poland, Portugal, Spain, Switzerland and the United Kingdom. Our results indicated that the daily growth rate in total confirmed cases of COVID-19 has a negative effect on the stock returns in the selected energy companies, while the daily growth rate in total deaths has also a statistically significant negative impact on the stock returns, but not as strong as the former one. The health crisis has affected the energy sector and we have to ensure energy for the future because it is the pilar that supports our civilization. Therefore, the governments and policy makers have to adopt policies and strategies that support the energy sector and the environment and the relevant investments.

Keywords COVID-19 · Stock Return · Energy

1 Introduction

The effect of the coronavirus pandemic (COVID-19) in the global economy is seen to be more severe than Great Depression's effect. It has caused not only infections and deaths in a global scale, but also it has affected the economy of most countries on the earth. Due to the coronavirus 2019 global pandemic, the uncertainty towards the future has increased. People are filling the uncertainty related to their

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jobs, to their own lives and their family's lives and to the entire economies. As a result of the infectiousness of the virus, the governments all over the world have tried to take measures to prevent the virus spread, such as shutdowns/lockdowns for social distancing, investing in buying special tests to be to the citizens for the virus recognition, putting people in quarantine that are infected by COVID-19, increasing the hospitals' capacity to treat the sick people from the confirmed cases, putting the people who travel from one country to another in a fourteen day quar-antine in order to prevent the spread of the disease. Although the number of deaths is decreasing, the pandemic is ongoing and the total scale of the disaster is still unknown, as well as the cost in the global economy. These issues are of a great interest for the near future.

On June 5, 2020, according to realtime statistical data eleased by Johns Hopkins University, selecting three months period, on June 30th, 2020 there have been diagnosed with COVID-19 6,601,349 people and have died 389,620 of them. On September 30th, 2020 there have been diagnosed (with Covid-19) 6,601,349 people and have died 389,620 of them. On December 31st, 2020 there have been diagnosed (with COVID-19) 6,601,349 people and have died 389,620 of them. The coronavirus pandemic hit the various markets at different dates. The USA market was hit on February 27, 2020 whereby the NASDAQ-100, the S&P 500 Index, and the Dow Jones Industrial Average indices dropped more than they did in the Global financial Crisis (GFC) in 2008. The FTSE index in the UK dropped more than 10% between Monday March 9th, to Thursday March 12th, 2020, its worst since Black Monday in 1987. These are signals of a great recession globally. The World Trade Organization predicted that global trade could decline by as much as 32% in 2020 (WTO 2020).

As other sectors, the energy sector is also affected by health crises and the consequences in the short and long-run term will be severe that could constrain the development of sustainable energy with low emissions and could not be able to ensure energy for future generations. During 2020 the global energy demand decline by 4%, which was the largest decline since World War II. This decrease in energy demand will have after effects in the long-run. Health crises in energy sectors create great challenges that serve as a guide to take lessons and find solutions and open opportunities for the post pandemic years. Analyzing this sector and the implication on economic development is a crucial task for policymakers and governments towards targets to promote renewable energy deployment that contribute to achieve the United Nation's Sustainable Development Goals (SDGs). Thus, sustainability of energy sectors will combat the lack of energy for the future and will reduce the negative effect on the environment, through renewable energy sources. European Union is becoming a leader in energy transition since global yearly emissions caused by EU countries are only 10%. Useful tools are developed in EU to support the energy transition. For the first time the carbon price pushed up over 20 Euro/tons due to reforms on the European Investment Bank, and the Emission trading System (ETS). In addition, maintaining carbon neutrality by 2050, requires enforcement of climate targets and rising the

2030 targets[1] (Mazzega et al. 2020). Energy security is an ongoing discussion but energy companies should rely more on sustainable use of RES, which means more utilization of renewable energy sources and deceasing reliance on traditional sources that protect companies from different risk exposures such as health crises (Koulouri and Mouraviev 2019).

The objective in this study is to investigate the impact of the COVID-19 pandemic on the stock returns of companies in the energy industry in Europe. In order to achieve this goal, two indicators are used: (1) the daily growth in total confirmed cases of COVID-19 and (2) the daily growth in total deaths due to COVID-19.

The rest of the paper is organized as follows: the next section presents the relevant re-view of literature. The third section contains the data, the methodology and the testable hypotheses. The fourth section depicts and analyses our empirical results, and the final section summarizes the paper and offers future research ideas.

2 Literature Review

COVID-19 crisis can have economic damages that are unpredictable, and the spillover effects are present in every area of the globe (Goodell 2020). In addition, he explained that the financial sector including stock market, banking and insurance companies are influenced by the wide range impact of the pandemic that serves as a starting point for researchers to investigate its impact.

Previous studies have identified several events that can affect stock market returns such as environmental, news, disasters, and political events (Famaand et al. 1969; Xu-et al. 2020). However, there are few studies that examine specifically the impact of the shock of pandemic diseases on stock market returns and the behavior of investors, who under the new health conditions change their investment preferences and strategies. Goh and Law (2002) found that the 1997 Asian financial crisis and the 1998 Hong Kong avian influenza outbreak had a significant negative impact on tourism. Chen et al. (2007), Chen et al. (2018) studied for Taiwan the impact of SARS on the hotel industry and found that SARS caused the stock prices of the hotel industry to drop. Lee (2020) studied for the US the impact of flu on stock market returns and found that it was negative, since an increase in the flu rate would reduce trading activities and thus stock returns. Ping et al. (2018) studied the long-term impact of the SARS epidemic on four major stock markets in China and Asia and found that it has a significant impact on the financial integration of the stock market.

Recent studies that investigate the influence of pandemic diseases on stock returns rely on country level and there is a lack of studies on firm level, especially in the energy sector in the European Union. For instance, Ashraf (2020) conducted a study in 64 countries over the period from January 22, 2020 to April 17, 2020 and revealed that the increased number of confirmed cases with COVID-19 had a negative effect on

[1] 2030 climate and energy package targets require that the share of renewables to be 32% of final energy consumption by 2030.

the stock markets returns. While the stock market response to the growth in number of deaths due to COVID-19 was weak. Stock market returns - responded quickly to this health crises but in the long-run the effect on stock market prices will depend on the severity of the disease outbreak. Al-Awadhi et al. (2020) investigated the effect of the COVID-19 coronavirus on the Chinese stock market and found that both the daily growth in total confirmed COVID-19 cases and deaths caused significant negative effects on stock returns across all companies of the Chinese market.

Fu and Shen (2020) studied the performance of China's energy companies during the outbreak of COVID-19 and found that the pandemic had a negative effect on the corporate performance of the companies in the energy industry sector. COVID-19 hurt productivity in the energy sector, causing companies' revenues to drop. The companies failed to cover fixed costs and expenses, because they had to implement plant shutdowns and personnel isolations, which eventually led to a sharp decline in the corporate performance which was proxied by the return on net profit.

Gharib et al. (2021), Gil-Alana and Monge (2020) examined the relationship between crude oil and gold spot prices, if there was any causality relation between them and how they were affected by the COVID-19 pandemic. The price of the crude oil dropped so much that it became negative on April 2020. This oil price crash increased the global panic and uncertainty. Their empirical results distinguished two significant periods in 2020 when oil prices dropped significantly. The first period was from March 6 and April 1, 2020, and the second from April 14–29, 2020. Their explaination for the oil price decrease in the first period was the negative oil demand due to the COVID-19 lockdowns and border closures. Their explanation for the oil price decrease in the second period was the oil price war of 2020 between Russia and Saudi Arabia and the low capacity of countries for storing the oil reserves. Hence, on April 21, 2020, the price of crudeoil WTI dropped below zero for the first time in recorded history at minus thirty nine dollars per barrel (-$39).

They found a bilateral contagion effect between oil and gold prices that should be taken into consideration by policy makers and investors.

Gurav (2020) found that the coronavirus pandemic spread fear and uncertainty. Hence, investors having these negative feelings were influenced on their investments decisions and consequently there were negative impacts on the stock market prices. Baig et al. (2020) for the USA found that daily announcements of confirmed cases of COVID-19 infection and deaths caused a significant increase in market illiquidity and volatility. Haroon and Rizvi (2020) found that COVID-19 Media coverage caused "overwhelming panic" regarding financial market reactions. Samuel et al. (2020) explored the effect of COVID-19 infection on public sentiment and found that it resulted in "extreme feelings, emotional and mental healthcare issues", detecting the presence of "high fear, confusion and volatile sentiments".

Goodell and Huynh (2020) studied the reaction of 15 USA industries to sudden COVID-19 related news announcements. They found positive reaction (positive abnormal returns) of the medical and pharmaceutical industries and negative reaction of the tourist industries, restaurants, hotels and motels, services and utilities.

Salisu and Adediran (2020) for the USA market found that uncertainty due to the infectious disease of COVID-19 increased energy market volatility implying that investors in the energy market may need to consider this COVID-19 health in the valuation of risk-adjusted returns for energy stocks in their portfolio.

Huo and Qiu (2020) examined how China's stock market reacted to the coronavirus pandemic in 2020, specifically to the pandemic lockdown announcement. The retail industry had a strong negative reaction to the COVID-19 outbreak, while the pharmaceutical and biotechnology, the computer and electronics industries had a positive reaction. Another related study for China is by He et al. (2020) who studied the market reaction and response trends of Chinese industries to the coronavirus pandemic. They applied event study methodology and their results indicated that the COVID-19 pandemic had a severe negative impact on industries, such as transportation, mining, electricity and heating, and environment, while it had a positive effect on manufacturing, information technology, education, and health industries.

Regarding studies on the energy sector, apart for the markets of the USA and China, we have found one for the market of Turkey and one for the market of Greece, the only study for the energy industry in Europe. Ertuğrul et al. (2020) analyzed the effect of the COVID-19 health crisis on the volatility of the Turkish diesel market and found that a high volatility pattern begun around mid-April, 2020 and peaked on May 24th, 2020. The explanations they offered were the government imposed weekend curfews and the bans on intercity travels. Polemis and Soursou (2020) examined the impact of the COVID-19 pandemic on the stock returns of 11 Greek energy listed companies. Using event study methodology they found that the impact depended on the event window they selected and that for all the windows they tried, there was a divergence of reaction among the Greek energy companies. In brief, on the day-5, most of the energy firms had a strong negative reaction but three of them had a strong positive one. On day 0 the market reaction of all the 11 firms was negative and significant since the investors expected the lockdown. However, the next day, day+1, most of the energy companies achieved positive abnormal returns and after the 10 day they were all recovered.

Shaikh (2021) examined the relation between COVID-19 and the energy market crisis for the USA and China through an unconditional analysis, a conditional volatility framework, and an investors' sentiment model in terms of energy stocks, energy futures, energy EFTs, and energy market sentiment index (VIX). He found that the daily announcements about COVID-19 infection cases and deaths had impacted the energy stocks and futures market negatively. He also found that the rising cases of COVID-19 infection based on the OVX index that presents the investors' sentiment in the energy market and the VXXLE, a volatility index of the energy sector, the COVID-19 pandemic had caused "a significant amount of panic and fear among the energy investors". This put a significant pressure on the energy options, since market participants worried of how to protect their energy investments which caused the risk premium and the volatility of the energy market to increase in the USA and China. So, based on the literature, we expect to find a negative impact of the COVID-19 pandemic on the stock returns of companies in the energy industry in Europe, which to our knowledge has not been done yet and this is our contribution to the pertinent literature (Fig. 1). As it is shown in the study of Shaikh (2021) the effect of pandemic crises has a negative effect on crude oil and future market.

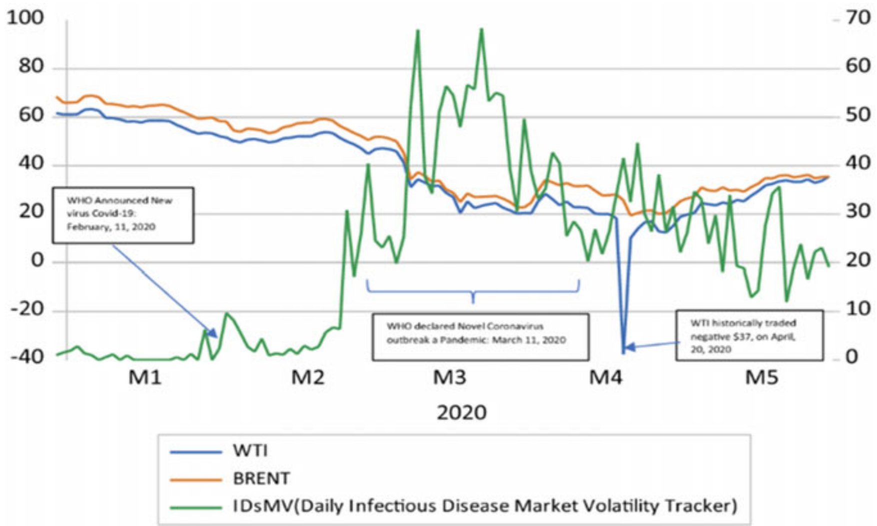


Fig. 1 Pandemic infection in the crude oil futures market. *Source* Shaikh (2021)

3 Data, Methodology and Testable Hypotheses

3.1 Data

To investigate the impact of this health crisis on the stock returns of companies in the energy industry, we focused on the top 100 Global Energy Leaders. Out of these 100 leading energy companies we selected only the European ones which were 43. The database we used to derive our necessary data for the sample companies is the Thomson Eikon database. For four (4) of them there was no available data. Hence, the final sample of our study is consisted of 39 companies. These are listed on the following site that has the 100 leading energy companies of Europe: https://www.thomsonreuters.com/en/products-services/energy/top-100.html.

The sample companies are presented in the Appendix A. In this study, daily data on the number of confirmed cases and deaths from COVID-19 were employed. This data was retrieved from the Coronavirus Source Data that has information for more than 200 countries and regions (https://ourworldindata.org/coronavirus-source-data). The data on daily stock prices was collected from the Thomson Eikon database. Also, certain firms' characteristics were included in the study to examine their impact on stock returns. As it is suggested by Al-Awadhiet al. 2020; Claessenset al. 1995, firm size is imperative for the companies' financial performance and therefore, market capitalization was used as a proxy for company size. Market-to-book ratio is another firm-specific variable that is equal to book value divided by market value and is considered as a more consistent variable to explain stock returns (Zhang 2013). Based on these studies daily data for market capitalization and market-to book ratio were retrieved for each sample company from the Thomson Eikon database as it was done for the stock prices.

The data for all the sample companies were collected from the date when the first COVID-19 case was confirmed in a European country that the company is listed. The first case was confirmed on January 24th, 2020 in France. Thus, the data were collected from January 24th, 2020 until December 31st, 2020, when the crisis reached the lower level in having very few cases and deaths from COVID-19.

3.2 Methodology

The number of confirmed cases and deaths has changed frequently during the period and the pandemic peak was not the starting point in time. Thus, in order to examine the effect of COVID-19 on stock returns in energy companies, panel data regression is used. Following Al-Awadhi et al. (2020) and Ashraf (2020) this study used panel data analysis technique over the classical event study methodology, since the present health crisis is not a one point of time event, but the spread of COVID-19 evolves over many days and weeks in a country. Also, this approach is better in capturing the time varying relationship between dependent and independent variables. In additional, applying panel data regression reduces estimation biased, multicollinearity problems and controls for individual heterogeneity according to Hsiao (2007) and Baltagi (2008).

We have identified the effect of COVID-19 on stock returns through (1) daily growth in total confirmed cases and (2) daily growth in total cases of death from COVID-19. In additional, firms' specific factors are included in the model as given by Eq. (1).

$$RE_{i,t} = \alpha_{01} + \alpha_{02}C19_{i,t-1} + \alpha_{03}LMCAP_{i,t-1}\alpha_{03} + MTB_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

where $\boldsymbol{RE_{i,t}}$ is the return of stock i on day t, taking log price differences, $\boldsymbol{C19_{i,t-1}}$ is the daily growth in number of confirmed cases on day t-1, or the daily growth in total cases of death on day t-1. While $\boldsymbol{LMCAP_{i,t-1}}$ is a firm specific factor that expresses daily market capitalization in natural logarithm representing company size. $\boldsymbol{MTB_{i,t-1}}$ is the market-to-book ratio of firm i on day t-1 that represent firm's worth.

Specifically, we run three versions of the above model of how the daily growth of COVID-19 cases affects the stock prices of the energy companies: The first version examined only the effect of the daily growth of COVID-19 cases on stock returns. The second version whereby the independent variables were two, the daily growth in COVID-19 cases and the market to book ratio as a more consistent variable to explain stock returns, investigated the effect that the two variables had on stock returns. Finally, the third version, whereby the independent variables were three, the daily growth in COVID-19 cases, the market to book ratio and the market capitalization which is a proxy of company size, examined the effect that the three variables had on stock returns.

We also run three versions of the above model to test how the daily death announcements by COVID-19 affected the stock prices of the energy companies: The first version examined only the effect of the daily deaths from COVID-19 cases on stock returns.-The second version whereby the independent variables were two, the daily deaths from COVID-19 cases and the market to book ratio as a more consistent variable to explain stock returns investigated the effect that the two variables had on stock returns. Finally, the third version whereby the independent variableswere three, the daily deaths from COVID-19 cases, the market to book ratio and the market capitalization which is a proxy of company size, examined the effect that the three variables had on stok returns.

3.3 Testable Hypotheses

The COVID-19 announcements regarding the cases and the deaths in each country were announced from the beginning of the pandemic appearance on the daily news and still are. This daily bombardment of disaster and death has caused to the people who listen to the news feelings of fear, anxiety and panic. Some of this people are investors. These negative feelings influenced the investors' behavior and decision making, affecting the stock markets, the companies of all the sectors and the economy as a whole. We think that since death is a permanent condition and irreversible, the death announcements due to the pandemic, will cause more fear in the investors and will cause a stronger reaction in the market. The government policies with the measures of closing the companies and the factories, of total or partial lockdowns and of travel prohibitions or restrictions have hurt the companies in the energy sector from many aspects. For instance, when the factories and power plants are closed or operate on reduced personnel they cannot be as efficient as before the crisis, since they do not operate at full capacity.Hence, their productivity will drop and their revenues and performance will decrease. Based on the above regarding the COVID-19's impact on the various economies and the consequences to the individuals and the companies, we formulate our testable hypotheses as follows:

H1: The COVID-19 pandemic case announcements are expected to have a negative impact on the energy companies in Europe as measured by their stock returns.

H2: The COVID-19 pandemic death announcements are expected to have a negative impact on the energy companies in Europe as measured by their stock returns.

H3: The COVID-19 pandemic death announcements are expected to have a stronger negative impact on the energy companies in Europe as measured by their stock returns, compared to the COVID-19 pandemic case announcements.

H4: The size of the listed companies in the Energy industry, as proxied by their market capitalization, is expected to affect their stock returns, in conjunction to the COVID-19 pandemic cases or deaths announcements.

4 Presentation and Analysis of Results

Table 1 presents descriptive statistics of the top 39 renewable energy companies in Europe—from January 24th to December 31st, 2020. As it can be seen the mean value of stock returns is negative during the period equal to -0,028% (-0,00,028), the minimum value is -67.8% and the maximum return is 71.75%. The highest growth rate in daily total confirmed cases from COVID-19 is 700%, and the highest daily growth of total deaths from COVID-19 is 460%. However, the average growth rate in COVID-19 cases is only 4,78% and the average daily growth death rate is 4,16%.

Whereby the variable StockReturns is the daily Stock Return of each sample company calculated as ln(Close price/Close price (t-1)); the variable GrowthTCC is the daily growth of total confirmed COVID-19 cases; the variable DGTDC is the daily growth of deaths due to COVID-19; the variable Markettobookratio is the Market to Book ratio and the variable mkt cap is the market capitalization, the proxy variable for company size.

Figure 2 shows the average stock returns for the sample energy companies from the first day in which was confirmed the first case infected by COVID-19 until the 31st of December 2020. As it can be seen the stock returns drop and become negative in the first days of the announcement for confirmed cases. However,the major reaction of the stock returns takes occurs some days after the first announcement of new confirmed cases of COVID-19.

Figure 3 shows the average of total cases for countries in which the companies are operating. Countries that have the highest number of the total cases per day are France, Spain United Kingdom Italy and Germany. The lowest number of infected people per day are Greece, Norway, Luxembourg and Finland. The announcement related to total cases for each country is expected to effect the stock return of companies that have their headquarters in these countries. Figure 4 shows the average total deaths for countries in which energy companies have their headquarters. The results show that countries that have the highest number of deaths are United Kingdom, Italy, France, and Spain, while Luxembourg is the country in which the data related to deaths are lower.

Table 2 presents the correlation matrix of all variables included in the model. All the correlation coefficients between variables are less than the threshold of 0.8 -which means that the model is not suffering from multicollinearity problems, except

Table 1 Descriptive statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Stock Returns	8,782	−0.00028	0.048063	−0.67827	0.717542
GrowthTCC	8,773	0.047805	0.192824	−1	7
DGTDC	8,126	0.041651	0.180472	−0.06671	4.6
Markettobookratio	8,821	72.14292	227.5085	0.002	1202.5
Mkt cap	8,821	8.715958	2.181133	−1.24287	12.07402

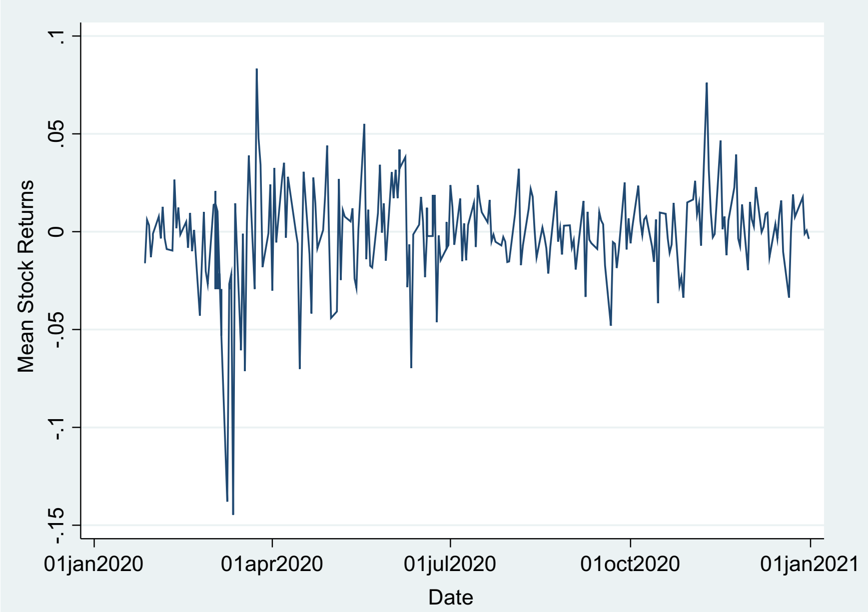


Fig. 2 Average stock market returns. *Source* Authors own elaboration

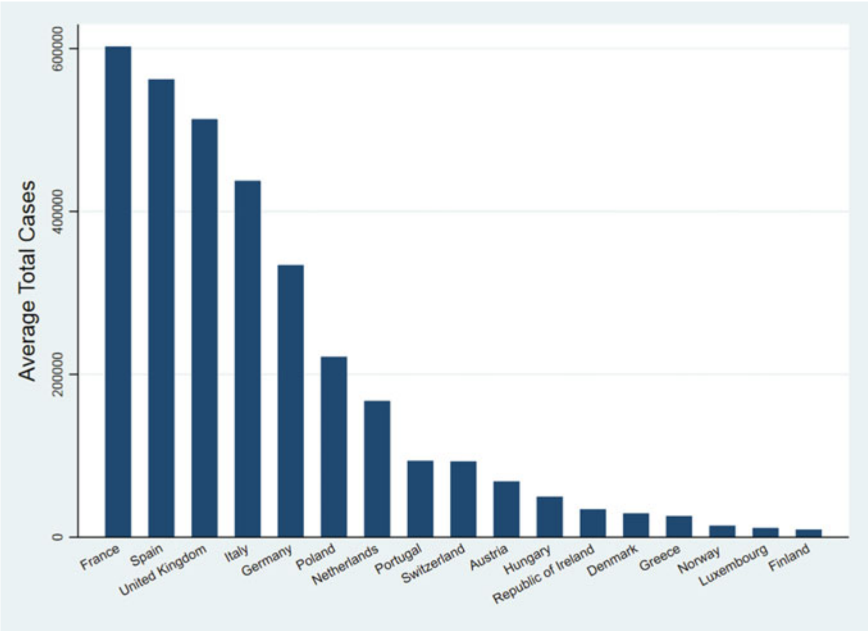


Fig. 3 Average total cases. *Source* Authors own elaboration

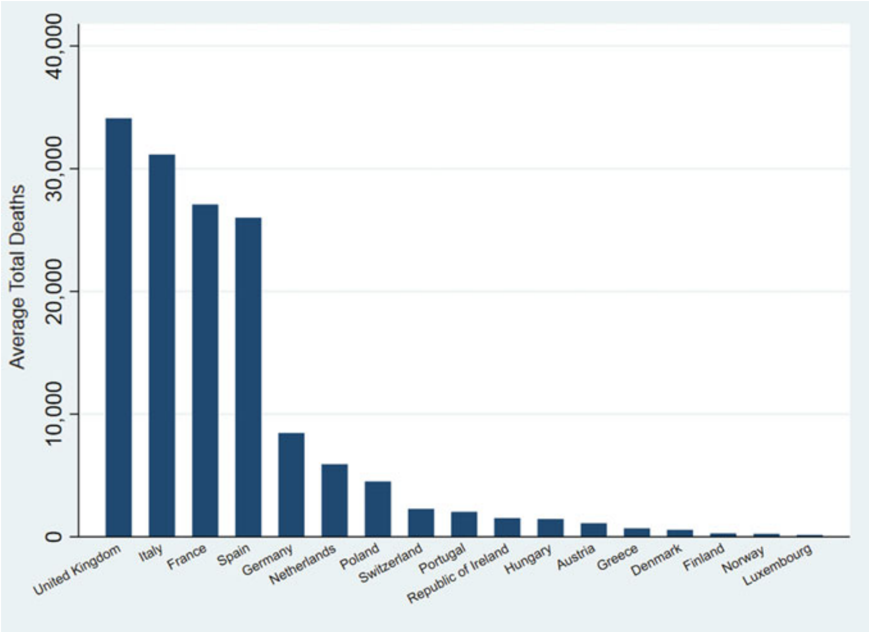


Fig. 4 Average total deaths. *Source* Authors own elaboration

Table 2 Pairwise correlations

Variables	StockReturns	GrowthTCC	DGTDC	Markettobook ratio	Mkt cap
StockReturns	1.000				
GrowthTCC	−0.072*** *p = 0.000*	1.000			
DGTDC	−0.067*** $p = 0.000$	0.606*** $p = 0.000$	1.000		
Markettobookratio	−0.000 $p = 0.9661$	0.019* $p = 0.0721$	−0.002 $p = 0.8499$	1.000	
Mkt cap	0.005 $p = 0.635$	0.000 $p = 0.983$	−0.005 $p = 0.6519$	0.129*** $p = 0.000$	1.000

***Indicates significance at the 1% level of a two tailed test, $p < 0.01$,
**Indicates significance at the 5% level of a two tailed test, $p < 0.05$,
*Indicates significance at the 10% level of a two tailed test, $p < 0.1$
Whereby the variable StockReturns is the daily Stock Return of each sample company calculated as ln(Close price/Close price (t−1); the variable GrowthTCC is the daily growth of total confirmed COVID-19 cases; the variable DGTDC is the daily growth of deaths due to COVID-19; the variable Markettobookratio is the Market to Book Value ratio and the variable mkt cap is the market capitalization, the proxy variable for size

from the correlation between the market to book value ratio and the market capitalization. As it can be seen there is a negative correlation between stock returns and the daily growth of total confirmed cases and the daily growth of total death cases - by COVID-19. There is a strong negative relation between the firms' stock returns and the COVID-19 pandemic case announcements, (r = −0,072 significant at the 1% level of a two tailed test). There is also a strong negative relation between the firms' stock returns and the COVID-19 pandemic deaths announcements, (r = -0,067 significant at the 1% level of a two tailed test). There is no linear relation either between the firms' stock returns and the market capitalization, (r = 0,005 not significant statistically). There is no linear relation between the firms' stock returns and the market to book value ratio (r = − 0,000 not significant statistically). Furthermore, there is a positive relation between the COVID-19 pandemic case announcements and the COVID-19 pandemic death announcements (r = 0,606 significant at the 1% level of a two tailed test). The relationship between size and the market to book value ratio is positive (r = 0,129 significant at the 1% level of a two tailed test). Also, there is no linear relation statistically significant between the COVID-19 pandemic case announcements and the market capitalization, (r = −0,000), while the relation between the COVID-19 pandemic case announcements with the market to book value ratio is positive (r = 0,019 significant at the 10% level of a two tailed test). Finally, there is no linear relation statistically significant between the COVID-19 pandemic death announcements and the market capitalization, (r = -0,005), as well as the market to book value ratio (r = −0,002).

In order to estimate the effect of COVID-19 on the stock returns of the selected energy companies in Europe, it is needed that all variables included in the model to be stationary. Using Levin et al. (2002) and Im et al. (2003) test for stationary we fail to reject the null hypothesis that no unit root is present in the data. All the variables included in the model are stationary. In order to decide the appropriate model for panel analysis, we performed Hausman test. The test results show that the Fixed effects model is better than the Random Effects model in which p-value = 0.000, which means that we reject the null hypothesis that Random Effects is preferred.

Table 3 reports the fixed effect panel data regression in which we include the variable daily growth of total confirmed COVID-19 cases. To deal with heteroscedasticity problems, we use robust standard errors for all variables in the regression. In all three versions of the model the effect of daily growth in confirmed cases is statistically significant and it has a negative effect impact on stock returns.

The market-to-book value variable in version (2) has a negative effect on stock returns that it can be explained by the fact that firms that have overvalued stock prices tend to have lower stock returns during the pandemic crises (Anh and Gan 2020). In version (3) market capitalization has a significant negative effect on stock returns, which means that the size of the company during the COVID-19 period has a negative effect on stock returns.In other words, as the daily case announcements increase, the stock prices of the larger companies drop more than the prices of smaller companies.

Table 4 reports the fixed effect panel data regression in which we include the variable daily growth of death cases due to COVID-19. To deal with heteroscedasticity problems, we use robust standard errors for all variables in the regression. In

Table 3 Regression of Daily Growth of Total Confirmed Cases on Stock Returns

Variables	(1) Stockreturns	(2) StockReturns	(3) StockReturns
GrowthTCC	−0.00989*** (0.00304)	−0.00921*** (0.00309)	−0.00840*** (0.00413)
Markettobookratio		−7.11e-05*** (1.25e-05)	−1.37e-05*** (2.03e-05)
Mkt cap			-0.0196*** (0.00356)
Constant	5.58e-05*** (0.000136)	0.00518*** (0.000937)	0.171*** (0.0303)
Observations	6,935	6,935	6,935
Number of companies	39	39	39
R-squared	0.001	0.002	0.014

*** Indicates significance at the 1% level of a two tailed test, $p < 0.01$,
**Indicates significance at the 5% level of a two tailed test, $p < 0.05$,
*Indicates significance at the 10% level of a two tailed test, $p < 0.1$
Whereby the variable StockReturns is the daily Stock Return of each sample company calculated as ln(Close price/Close price (t−1); the variable GrowthTCC is the daily growth of total confirmed COVID-19 cases; the variable DGTDC is the daily growth of deaths due to COVID-19; the variable Markettobookratio is the Market to Book Value ratio and the variable mkt cap is the market capitalization, the proxy variable for size

Table 4 Regression of Daily Growth of Total Deaths Cases on Stock Returns

Variables	(1) Stockreturns	(2) Stockreturns	(3) Stockreturns
DGTDC	-0.00277*** (0.00293)	-0.00289*** (0.00291)	-0.00457*** (0.00292)
Markettobookratio		-0.000145*** (3.10e-05)	-7.31e-05*** (2.58e-05)
mkt cap			-0.0233*** (0.00319)
Constant	0.000243** (0.000119)	0.0102*** (0.00211)	0.208*** (0.0272)
Observations	6,418	6,418	6,418
Number of companies	39	39	39
R-squared	0.0001	0.002	0.016

Robust standard errors in parentheses
***Indicates significance at the 1% level of a two tailed test, $p < 0.01$,
** Indicates significance at the 5% level of a two tailed test, $p < 0.05$,
*Indicates significance at the 10% level of a two tailed test, $p < 0.1$

all three models the effect of daily growth of death cases is statistically significant and it has a negative impact on stock returns. We observe however, that this negative effect on stock prices is not as strong as in the previous regression (Table 3) with the independent variable of total confirmed COVID-19 cases as the explanatory variable of the stock returns. In Table 4, the regression results show that in all three models the effect of the daily growth in total death cases has a statistically significant negative effect on stock returns. Also, Appendix B shows the negative correlation between fitted value of stock returns and total cases.

In Table 4, the market-to-book value variable in version (2), has a negative effect on stock returns that it can be explained by the fact that firms that have overvalued stock returns tend to have lower stock prices during the pandemic crises according to Anh and Gan (2020). In version (3) the market capitalization has a significant negative effect on stock returns, which implies that the size of the company during the COVID-19 period has a negative impact on stock returns, in other words, as the daily death announcements increase, the stock prices of the larger companies drop more than the prices of the lower capitalization companies.

Whereby Stock Return is the Dependent variable calculated as ln(Close price/ Close price (t-1) and the Independent variables are: The DGTDC which is the daily growth in total deaths due to COVID-19, the Market to book value ratio and the Mkt cap which is the market capitalization, the proxy for size.

Therefore, based on our statistical results from Tables 2, 3 and 4 we derive the following inferences: The results from Tables 2 and 3 support our first hypothesis, since the COVID-19 pandemic case announcements had a significant negative effect on the stock returns of the energy companies in Europe. This result is consistent with the studies of Mctier et al. (2013), Xu et al. 2020 for the US companies, Ashraf (2020) for 64 markets globally, Fu and Shen (2020) for the energy companies in China and Pinglin et al. (2020) for the electricity and heating companies in China, too.

The results from Tables 2 and 4 support our second hypothesis, since the COVID-19 pandemic death announcements had a significant negative effect on the stock returns of the energy companies in Europe. This result is consistent with the studies of Xu et al. (2020), Ashraf (2020) for 64 markets globally, Fu and Shen (2020) for the energy companies in China and Pinglin et al. (2020) for the electricity and heating companies in China, too. Also, Appendix B shows the correlation between announcments of deaths and fitted value of stock returns which is negative.

Surprisingly, our results reject the third hypothesis, since the COVID-19 death announcements did not have a stronger negative effect on the stock returns of the energy companies compared to the COVID-19 case announcements' effect, based on the regression coefficients in all three versions of the two models in Tables 3 and 4. This result is partially consistent with the study of Ashraf (2020), who found that the case announcements with COVID-19 had a negative effect on the stock markets returns, while the death announcements effect was weak, insignificant. However, we found a significant negative effect on stock returns of the death announcements, but just not so strong as the one of the case announcements. Apergis and Apergis (2020) examined the effect of the Covid-19 pandemic on the Chinese stock market. They found that daily increases in death cases due to Covid-19 had a stronger significant negative effect on the stock returns compared to the disease only cases of the Covid-19. Therefore, our results agree partially with Apergis and Apergis (2020), in the fact that the market reaction to the death announcements is negative and significant, but disagree in the part that death announcements cause a greater negative reaction. These authors focused on China, while we focused on Europe and the cultural differences could be an explanation for this different and unexpected result.

Regarding our fourth hypothesis, based on the results in Table 2, the correlation of stock returns and market capitalization was not significant. However, when we run the regression in both models, with the case and the death announcements, in the third version of each model, the regression coefficient of the market capitalization as a third explanatory variable was statistically significant and negative, equal to −0.0196 ($p = 0.00356$) in Table 3 and equal to −0.0233 ($p = 0.00319$) in Table 4. This implies that the size of the sample energy companies in general does not affect their stock returns, since they were all from the list of the 100 leader energy companies, but, under the conditions of bad health news, here the pandemic cases and deathannouncements, the company size plays a significant role in the market reaction. Hence, the results support our fourth hypothesis. The relation of size and the case or death announcements is not significant based on the correlation coefficients in Table 2. However, under the conditions of the pandemic bad news announcements, the effect of size to the market returns is significant and negative. The larger companies are hit stronger by this health crisis, since the higher the exposure to risk, the lower the stock returns. We have a case of a negative signaling effect. To mitigate the negative effects of health crises in the near future for energy companies it is required that each EU member country follows an energy policy towards energy transition in order not to have differences between declared goals and the implemented energy policies (Croonenbroeck and Lowitzsch 2019).

5 Summary and Concluding Remarks

In this study, we examined the effect of COVID-19 on daily stock returns of 39 leading energy companies in Europe during the period from January 24th to December 31st, 2020. The fixed effects model is considered as the most suitable in our data and the results of the panel regression models show that the announcements about the number of daily total confirmed cases infected by COVID-19 have a significant negative effect on stock returns, while the daily growth in total deaths announcements caused by COVID-19 have a significant negative effect, but it is not as strong as the one from the case announcements.

The market capitalization influences negatively the stock returns for the sample of European leading energy companies. This means that large market capitalization firms experience significantly more negative effects on their stock returns than small market capitalization firms. Furthermore, we found that the investors in the energy sector responded quickly to the health crisis and this caused a severe reduction on stock returns during March 2020. However, the effects continued for many months in which stock returns were volatile.

These findings suggest that the governments should pay attention to the fluctuations of stock returns due to a health crisis in order to take precautionary measures and adopt such policies to protect the stock markets from severe deterioration and investors from the uncertainty about the future status of their stocks.

The measures that are imposed by the governments at present, like the multiple lockdowns and the restrictions to the civilians/investors in working and moving as they were used to, increase the feelings of fear and anxiety among the civilians, cloud their decision-making processes in general and also in particular, regarding the selection of profitable investments.. The governments should formulate and apply such policies that would inspire trust in the markets and would attract investment capital so that the underlying economy will not be hurt severely or paralized by any health crisis in the future.

Energy is the crucial factor of our civilization so the energy companies are the pillars that support it by creating and distributing the power needed for all operations. The investments in the energy sector with considerations about protecting the environment are of major importance. Our study gives the empirical proof of the negative impact this health crisis had on the energy sector in Europe. There were some equivalent studies for the market of China that we discussed in the literature section, but none for Europe. Therefore, our study is of importance to the academicians because it enriches the relevant literature and to the policy makers of Europe because it can be a trigger for better strategic planning in the relevant areas. This negative effect of the COVID-19 health crisis can be seen as a challenge and not as a disaster, that brings changes and mobilization of resources in order to increase the efficiency of the energy companies and to ensure certainty under unexpected events.

The first limitation of our research is the size of our sample, which is small based on the population of the energy companies. However, we have selected the top 100 energy leaders of Europe and from this group only 4 are deleted. So we are restricted due to the nature of our criterion. The second limitation is the fact that we did not have access to the data whereby we could distinguish the sample companies in those that are conventional and those that are renewable energy companies, or both.

Future research could focus on investigating the effect of this heath crisis on the stock returns of all the energy companies in Europe and try to distinguish the factors that may differentiate this reaction for better understanding, for instance by geographical criteria or by the stage of market development (developed and developing markets), by capitalization and by the type of energy firms. Specifically, the conventional energy companies could have a very different reaction from the renewable energy companies that are younger in age, have more modern technology and other different characteristics that can be identified and tested.

Appendix A

Company Names Alphabetically And Country of Origin

Company from Stock index	Stock's Country	The day when 1st COVID-19 case was confirmed
Acea SpA	Italy	Jan 31, 2020
Aker Solutions	Norway	Feb 27, 2020
BP	United Kingdom	Jan 31, 2020
DCC	Ireland	Mar 2, 2020
E.ON SE	Germany	Jan 28, 2020
Électricité de France	France	Jan 24, 2020
Enagás	Spain	Feb 3, 2020
Engie	France	Jan 24, 2020
Eni	Italy	Jan 31, 2020
Galp Energia	Portugal	Mar 3, 2020
Global Pvq SE i I	Germany	Jan 28, 2020
Grupa Lotos	Poland	Mar 4, 2020
Hellenic Petroleum	Greece	Feb 27,2020
Hera	Italy	Jan 31, 2020
JOHN WOOD GROUP PLC	United Kingdom	Jan 31, 2020
MOL	Hungary	Mar 5, 2020
Motor Oil Hellas	Greece	Feb 27, 2020
National Grid	United Kingdom	Jan 31, 2020
Neste Oyj	Finland	Jan 30, 2020
OMV AG	Austria	Feb 25, 2020
Ørsted	Denmark	Feb 27, 2020
Pennon Group	United Kingdom	Jan 31, 2020
PKN Orlen	Poland	Mar 4, 2020
Repsol	Spain	Feb 3, 2020
Royal Dutch Shell	Netherlands	Feb 28, 2020
Rubis	France	Jan 24, 2020
RWE	Germany	Jan 28, 2020
Saipem	Italy	Jan 31, 2020
Saras	Italy	Jan 31, 2020
Siemens Gamesa Renewable Energy	Spain	Feb 3, 2020
Snam	Italy	Jan 31, 2020
Statoil	Norway	Feb 27, 2020
Weatherford International	Switzerland	Feb 26, 2020
Técnicas Reunidas	Spain	Feb 3, 2020

(continued)

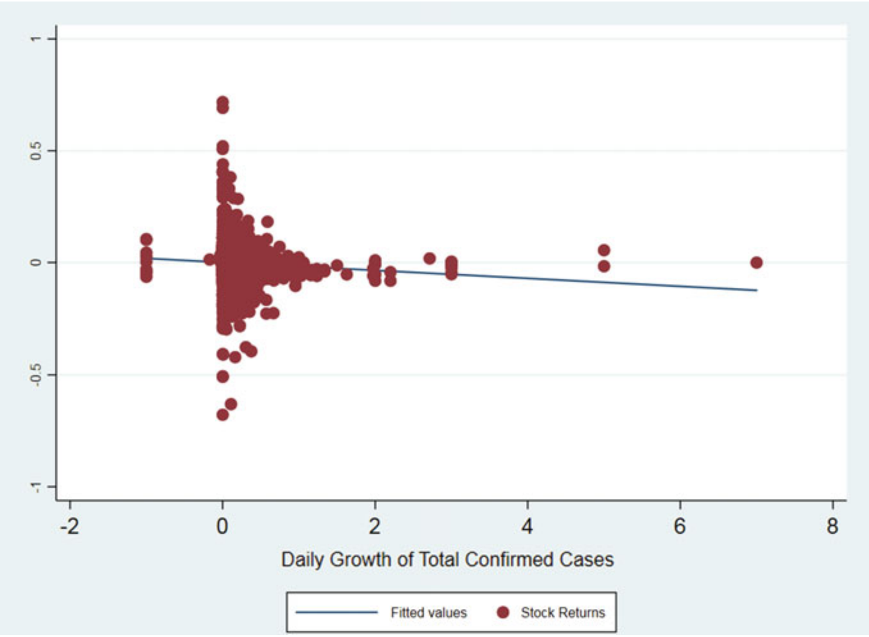
(continued)

Company from Stock index	Stock's Country	The day when 1st COVID-19 case was confirmed
Tenaris	Luxembourg	Mar 2, 2020
Total	France	Jan 24, 2020
Tullow Oil	United Kingdom	Jan 31, 2020
Vallourec	France	Jan 24, 2020
Vestas	Denmark	Feb 27, 2020

Source https://www.thomsonreuters.com/en/products-services/energy/top-100.html

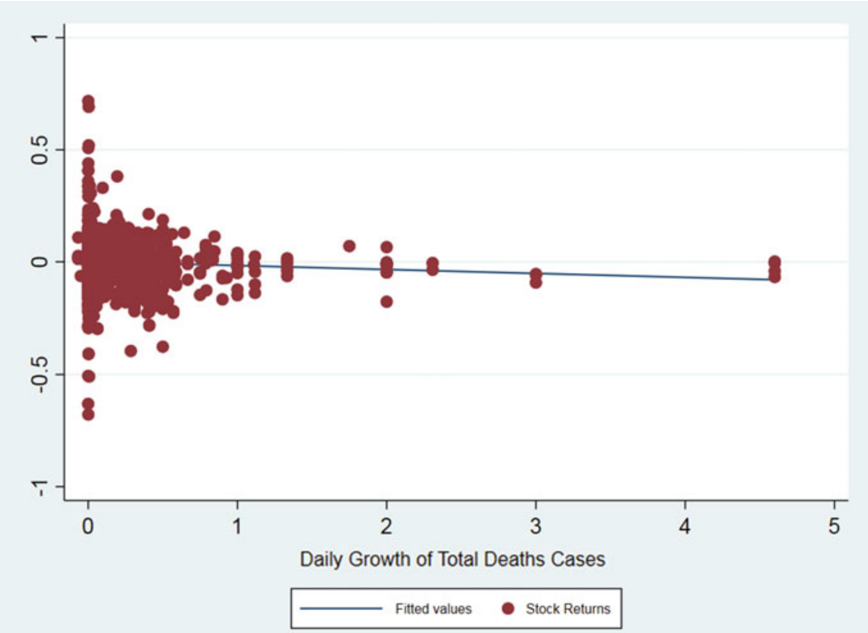
Appendix B

Scatter plot of correlation for variables Stock Returns and GrowthTCC



Appendix C

Scatter plot of correlation for variables Stock Returns and DGTCD



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Impact of Biofuels Production on Food Security on Selected African Countries

Corina Ene and Adrian Stancu

Abstract The significant and alarming increase of greenhouse gas emissions, as the main factor affecting the earth's climate raises worldwide concern and requires urgent developing of international and local policies that support the environment. At present, the importance of bioenergy in the context of climate change is globally recognized, and biofuels are considered as crucial elements of the future energy matrix which enhance and safeguard energy security. This chapter studies the complex relationship between bioenergy and food security, exploring the popular 'Food versus Fuel' debates and discussing the implications of biofuel on agricultural markets, which are strongly dependent on the particular context at local level. Clearly, fossil fuels should be substituted by non-conventional energy sources, and biofuels could be part of the answer, provided that their usage promotes environmental sustainability does not enter into unfair competition with food production sources. The analysis focuses on 2010–2019 period, and it points out the weight evolution of the world energy production by type of energy, the weight evolution of each type of renewable energy production, the countries with the lowest level of food security and their biofuels production, and the land deals engaged in Madagascar, Rwanda, Mozambique, and Sierra Leone by the EU and Non-EU companies.

Keywords Biofuels · Food security · Renewable energy · Non-renewable energy · Environmental sustainability · Land deals

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1 Biofuels. An Introduction

The increasing demands for energy in our contemporary society and mainly the rapid increase in greenhouse gas (GHG) emissions led to ongoing efforts in order to find alternative sources so that fossil fuels can be efficiently replaced using substituents deriving from eco-friendly processes (Khan et al. 2018).

Biofuels is the name of a wide category of solid, liquid, and gaseous fuel processed from:

- special energy crops—plant cultivated and used for energy generation by fuels extraction (including algae, microalgae and seaweeds);
- different sources such as: agroforestry, farming residues (including bran, stubble, animal blubber by-products), waste and sewage from paper manufacturing industry, waste material from construction sites (e.g., wood), decomposable waste materials (such as human waste, sewage sludge and manure, edible oils) (Jha and Schmidt 2021).

FAO [Food and Agriculture Organization of the United Nations] defines *biofuel* as "fuel produced directly or indirectly from biomass" (FAO 2021). Similarly, in the Eurostat Glossary, biofuels—defined as "fuels derived directly or indirectly from biomass"—are divided into three categories (Eurostat 2019):

- solid biofuels refer to solid organic, non-fossil material of biological origin (also known as biomass) which may be used as fuel for heat production or electricity generation (fuelwood, wood residues, wood pellets, animal waste, vegetal material, etc.);
- liquid biofuels include all liquid fuels of natural origin (e.g., produced from biomass and/or the biodegradable fraction of waste), suitable to be blended with or replace liquid fuels from fossil origin (biogasoline, biodiesel, bio jet kerosene, etc.) (Dusmanescu et al. 2016);
- biogases mean gases composed principally of methane and carbon dioxide produced by anaerobic digestion of biomass or by thermal processes from biomass, including biomass in waste (from anaerobic fermentation and from thermal processes).

The energy obtained from biofuels is also called "Bioenergy" (FAO 2021). Historically, the use of biofuel as an alternative to fossil fuel has been started since 1900, when the inventor of diesel engine, dr. Rudolph Diesel, used peanuts oil for the compression engine, while even earlier Nikolaus Otto (1832–1891) had designed his ignition engine to run on ethanol.

Biofuels are classified—on the basis of the sources they occur and their production—into *first, second, third and fourth generation* (Priya et al. 2021; Subramaniam et al. 2019; Long et al. 2015; Ajanovic 2011).

1. First-generation biofuels are conventional biofuels, using edible biomass as raw material. Biomass—including a large range of abundant renewable/organic sources (plants and waste)—refers to organic material which derives from

biological crops and different processes. It is obtained from different subsistence crops like maize, wheat, soybean, corn, sugarcane, rapeseed, and sunflowers. These biofuels are mostly blamed for only modest increases of agricultural value added in developing countries, creating additional risks of deforestation and threats to biodiversity (OPEC Fund for International Development 2009). Drawbacks of these biofuels include the following: low rate of fuel production compared to used land (e.g., for maize), the agricultural requirements are not always met (for sugarcane, for instance), some species face pests and diseases (soybean) or severely affects the food chain, since these feedstocks are also used for food and feed production. The two most common types of biofuels in use today are ethanol and biodiesel, while the four largest sources of biofuels are: maize, sugarcane (for bioethanol), soybean, and rapeseed (for biodiesel).

2. Second-generation biofuels are advanced biofuels manufactured by cellulosic or carbohydrate biomass, obtained from the different trees, grass, bushes (wood waste), agricultural residues, municipal solid waste. They are commonly extracted from non-edible matters of plants and farming, therefore do not compete with food and feed use. Some disadvantages derive from both the fact that soil requirements are difficult to meet and the inadequate effects on engines of waste unrefined vegetable oil.
3. Third-generation biofuels are focusing on the use of microscopic organisms and use algae as a source because it contains energy rich oils. The raw materials are photosynthetic organisms like diatoms, Euglena, and cyanobacteria. Biofuels based on algae seem to overcome past difficulties and do not compete with food for its obtaining, while CO_2 emissions are low when used for transport purposes, so they are more environmentally friendly.

   A study on third-generation biofuel investigating current researches on microalgae-based biofuel supply chain modeling underlines their limitations at operational level as they address mostly strategic and tactical decision-making (Abbasi et al. 2021). According to Abbasi et al. (2021), algae cultivation challenges include finding the optimal location and assessing land suitability (using integrated models), reduce the cost of biofuel production and making it compatible with conventional biofuels, including the concept of life cycle assessment of microalgae products, optimizing resource management, minimizing waste emissions in order to achieve environmental sustainability.
4. Fourth generation biofuels are produced with the help of genetic engineering of algae (micro algae, macro algae and cyanobacteria).

First- and second-generation biofuels have a number of inherent limitations that make them less ideal as long-term substitutes for fossil fuels, while third- and fourth-generation biofuels could become viable alternatives (Sână et al. 2011).

According to EnerData (2021), since 2008, European regulations (RED II directive) differentiate between conventional biofuels (first-generation) and advanced biofuels (second and third generation).

The aims of the chapter are, firstly, to analyze the weight evolution of the world energy production by type of energy between 2010 and 2019 to identify the trend of renewable energy as compared to non-renewable energies. Secondly, to analyze the weight evolution of each type of renewable energy production for the same period to emphasize their tendency in the following years. Thirdly, to describe the countries with the lowest level of food security and their biofuels production between 2010 and 2019 in order to underscore if their biofuel production had a negative impact on population's food security. Fourthly, the land deals engaged in these countries by the European Union [EU] and Non-EU companies were analyzed to highlight the cases of low food security.

2 Using Biofuels in the New Energy Era. Advantages and Disadvantages

In recent years, there was a dynamic growth in production of liquid biofuels, and, as a result, the increasing competition between biofuels and food production occurred in the case of first-generation biofuels, which are based on food raw materials (Kurowska et al. 2020).

Many studies based on statistical data show that the world production of liquid biofuels is growing dynamically, as it almost tripled in 2005–2018, from 49.9 billion liters to 167.9 billion liters. In 2018, in the EU, the growth of vegetable oil production allocated to energy purposes reached 72.5%. At the same time, grain conversion into bioethanol was very dynamic, both for wheat and corn production, while there was a decline in the final stocks of cereals. Also, in the same year, the global production of biofuels based on food raw materials (first-generation biofuels) reached 167.9 billion liters (bioethanol and biodiesel together), consuming "16.1% of maize grain, 1.7% of wheat grain, 3.3% of grain of other feed grains and 13.5% of vegetable oil" (Kurowska et al. 2020).

According to Subramaniam et al. (2020) production of renewable energy coming from biofuels has grown progressively in 2019 in both developed and developing countries.

For the last two decades, the growth in the global biofuel production was significant in the 2000s but slowed over the 2010–2019 period; after COVID-19 crisis severely affected biofuel sector even more that of fossil fuels, estimates indicates that 2021 production level could remain below its 2019 level (EnerData 2021).

An analysis of global dynamic of biofuels sector shows that despite the fact that conventional biofuels still cover most of global production, global biofuel production has seen a ninefold increase between 2000 and 2020, while: (a) North America and Latin America dominate bioethanol production; (b) North America and Latin America dominate ethanol consumption; (c) Europe and Asia dominate biodiesel consumption (EnerData 2021).

In the same respect, in 2021 the International Energy Agency [IEA] published a forecast for 2021 and 2022, stating that, even if total biofuel demand for transport declined with 8% to 150 billion liters in 2020 in contrast to 2019, global biofuel production is expected to recover to the 2019 level in 2021, yet unevenly. Also, while ethanol production is forecast to remain 3.6% below the 2019 amount largely due to Covid-19 crisis (which caused disruption of fuel demand), capacity expansions for biodiesel production allows for a 10% increase in 2021 as compared to 2019 (International Energy Agency 2021a).

Regarding the European Union, the final report of the Biofuels Research Advisory Council underlined the significant potential to produce biofuels (European Commission 2006). In 2006, ambitious targets for the development of biofuels were defined, as the vision expressed for 2030 proposed that one quarter of EU road transport fuel needs be covered by clean and CO_2-efficient biofuels. Yet, since there is a demand for biomass from agriculture and forestry between different sectors—food, feed, fibers, chemicals, and energy, biofuels should be produced using sustainable and innovative technologies, promoting the transition towards second generation biofuels and minimizing competition with food.

Later, The Europe 2020 strategy designed for sustainable and inclusive growth considered the share of renewable energy in final energy consumption as an important factor for achieving economic performance and competitiveness goals (Radulescu et al. 2018).

In the EU, ePURE Association is representing the interests of European renewable ethanol producers to the EU institutions, industry stakeholders, the media, academia, and the general public. In the context of the EU energy and climate policies under the European Green Deal, the 2020 ePURE report assessing progress of the EU and its Member States in meeting the 2020 objectives regarding the transport sector show that since 2004 the renewable energy share in transport has been steadily increasing to 8.0% in 2018, but additional efforts would have been necessary to meet the 10% 2020 target. (ePURE 2020).

Based on input from ePURE and the European Biodiesel Board, Bioenergy Europe has published its annual statistical report showing that the transport sector is still dominated by fossil fuels while it remains the main energy user and source of emissions. (ePURE 2021; Gurtu et al. 2017). Despite the fact that renewable ethanol has been the main driver in replacing fossil fuels in EU transport, the report concluded that the potential contribution of sustainable biofuels is limited by policies that hinder their use, thus compromising the achievement of Green Deal goals.

Moreover, the Farm to Fork Strategy [F2F] presented by the Commission strategy in May 2020, designed to establish a sustainable food system identified three main targets for the member states: “1. to ensure sufficient amounts of food at reasonable prices; 2. to contribute to the EU’s climate neutrality until 2050; 3. to guarantee decent incomes” (Kurowska et al. 2020).

According to the Commission, the F2F strategy established in May 2020 is an integral component of the EU Green Deal, where one of the objectives is to make a just, healthy, and eco-friendly food system, while the share of renewable energy.

Some of the most prominent *advantages* of using biofuels include (Priya et al. 2021):

- biofuels are environment friendly, allowing the reduction of CO_2 emissions, efficient production processes and less pollution;
- biofuels return high performance while being cost effective;
- for biofuels production, waste can be used as raw materials;
- biofuels production generates jobs locally;
- some biofuels are non-toxic and may be stored easily;
- biofuels are relatively less flammable than fossil fuel, so they provide a higher level of security in handling processes.

Instead, biofuels also have significant disadvantages which are crucial in determining their overall efficacy (Priya et al. 2021; Kurowska et al. 2020):

- biofuels could be more expensive than fossil fuel;
- biofuels provide less energy than conventional ones;
- biofuels production requires a significant energy consumption (however providing 30% more energy than the energy used in its production). Fossil fuels are used to produce biofuels, which further increases emissions, so that they may even add to the emission of greenhouse gases;
- the use of nitrogen fertilizers for crop production increases nitrogen oxide emissions and pollutes water and soil;
- some biofuels can damage rubber housing and seals in engine chamber;
- there are difficulties in the distribution and supply of produced biofuel. It requires advanced supply chain system;
- it could lead to turning food crops into fuel thus farmland becomes occupied for production of energy crops if the margin on biofuel is more attractive;
- since agricultural production goes to both the food market and the energy market, this will intensify agricultural production for non-food purposes, shrinking land availability for growing food and inducing unpredictable consequences for the natural environment;
- biofuels production requires extensive land areas, endanger forests, food crops and, accelerate global warming, and eventually lead to higher food prices;
- biofuels production may lead to other serious social and environmental difficulties;
- there are raising serious concerns about fuel vs. food conflict.

3 Fuel Versus Food: Are Biofuels Jeopardizing Food Security?

Given that biofuels production uses raw materials originating from agriculture and the associated land, many studies aimed at exploring their impact on food security. In this regard, Schmidhuber (2007) underlines that impact studies should differentiate between effects on different aspects such as availability, access and stability of food supplies.

Since 2008, the International Food Policy Research Institute [IFPRI] draws the attention on the fact that over the coming decades, global food and agricultural systems will have to face the competing needs of food, feed, and fuel, besides higher pressure from climatic and economic changes. In this regard, IFPRI identified the combination of drivers for increasing biofuel demand, with significant impact on global food systems: growing energy needs, rising oil costs, the pursuit of clean, renewable sources of energy, and the desire to boost farm incomes in developed countries (International Food Policy Research Institute 2008).

In 2008, the FAO report "The State of Food and Agriculture 2008" delivered several key messages in the context of the potential scale of the biofuel market, underlining that its impact on the food security of the poor should be of high priority on the political agenda. The summary of these key-messages highlights both constrains and opportunities deriving from the rising demand for biofuels (FAO 2008a):

- the growth in demand for liquid biofuels is one of the many factors that are responsible for the recent sharp increases in agricultural commodity prices;
- while biofuels will continue to induce rising pressure on commodity prices, poverty levels in developing countries could be affected, which calls for adequate measures to ensure access to food by the poor and vulnerable, especially for both low-income food-deficit countries and net food-importing developing countries;
- in the future, growing demand for biofuels can present an opportunity for promoting agricultural growth and rural development by offer income-generating opportunities for farmers in developing countries, provided government policies and support are available and equity- and gender-related risks issues are properly addressed.

The "*food security"* concept—closely linked to economic growth and social progress (Ene 2020) was associated with multiple definitions depending on the context, starting from the classic definition established by the FAO (2002, 2008b): a "situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life".

The correlation between biofuels and food security can be analyzed only taking into account its four main components or dimensions (Ene 2020; FAO 2008b):

- availability: having sufficient quantities of food available, provided by production, trade and stocks, on a consistent basis;
- access: having adequate resources for access to nutritious food; food access integrates three elements: affordability (economic access: incomes, purchasing power), preference (sociocultural values), and allocation (food logistics);
- utilization: having an appropriate food intake and the ability to absorb and use food nutrients. Food safety plays an important role in this context, alongside with the food nutritional value;
- stability: maintaining consistent food availability, access, and utilization despite various challenges and crises.

As a particular case, a Ghana case study on the distribution of food security impacts of biofuels shows that biofuel impacts on all four pillars of food security on household level are projected to negatively affect food prices and imports. This potential effect imposes caution regarding decision on the country biofuel production which should be made in the context of other developments (Brinkman et al. 2020).

Given its sourcing and obtaining processes, the conflict between biofuel and food is based on *two important correlated issues:* the competition for resources (mainly agricultural outputs) and the price of agricultural products. On this matter, the second chapter—Biofuels and household food security—of the FAO 2008 Report, "The state of food and agriculture in Asia and the Pacific region" draws the attention on the raising effect of the demand for biofuels on food prices, which will impact the food security of poor people in both rural and urban areas.

The most recent global report published by FAO, *The State of Food Security and Nutrition in the World 2021*, shows that in 2020, under the circumstances created by the COVID-19 pandemic, world hunger increased in 2020 as the number of undernourished people continued to rise, reaching between 720 and 811 million people (FAO et al. 2021).

The same report draws attention that the global targets for nutrition indicators and eradication of hunger cannot be achieved by 2030 (and around 660 million people may still face hunger) unless significant actions are taken to resolve the issue of food access.

In this context, agricultural inputs, which already seem insufficient, also provide intermediate inputs to the production of non-food commodities (such as maize for biofuel production).

Also, a 2013 report by the High Level Panel of Experts [HLPE] on Food Security and Nutrition of the Committee on World Food Security [CFS] on biofuels and food security states that biofuel policies have to integrate food security as a major concern (HLPE 2013).

As multiple challenges that the world faces today are inter-correlated, the necessary measures for achievement of the 2030 Sustainable Development Goals (SDGs) to end hunger and ensure access to modern energy for all should be based on understanding the nexus of food security, bioenergy sustainability, and resource management (Rehman et al. 2021; Hysa et al. 2020; Kline et al. 2016).

Subramaniam et al. (2019) investigated the nexus between food security and biofuel production for 56 developing countries over the period 2011–2016 and concluded that production of biofuels does have an impact on food availability, which calls for adequate policy measures.

Another important issue in this equation regards the *impact of biofuel production on food prices*, consequently multiple studies aimed to clarify this correlation which evolved differently over time. Thus, while a 2011 analysis concluded that "no significant impact of biofuels production on feedstock prices can be observed", starting with 2nd generation biofuels (Ajanovic 2011), recent research stated that biofuel production increases food prices by causing additional pressure on food supply and demand (Bilgili et al. 2020).

Regarding the 2007–2008 World Food Crisis, studies show that biofuels production may have been a possible cause of high rises in increased agricultural commodity prices (Bilgili et al. 2020; Rey 2013), amplifying the dilemma between biofuels development and food security (mostly its dimensions regarding availability of and access to food) (Ghosh et al. 2019). Other studies on food price crisis found that the growth of biofuel feedstock contributed between 20 and 50% to the price increase of maize, while land use change could lead to an increase by 1–2% for global maize and wheat, and by around 10% for vegetable oil (Center for Sustainable Systems [CSS] 2021).

A study carried out in 2017 estimated that, while about 40% of US corn being used to produce biofuels, world food prices could rise by about 32% by 2022 due to both the biofuel mandate and side effects on demand—in the form of "population growth and income-induced changes in dietary preferences" (Chakravorty et al. 2017).

In the same regard, the World Bank president stated that increasing biofuel production can be regarded as a significant contributor to soaring future food prices around the world (Subramaniam et al. 2020).

At the same time, other researchers consider that both food and biofuel production can be reconciled as both are significant to sustainable development, so that a combined solution should be found. It is logical that as demand from biofuels increases, it has an impact on agricultural commodity prices. However, several complex factors such as global commodities market competition and improving market mechanisms (physical infrastructure) could moderate price increases (Ghosh et al. 2019).

On the contrary, to the dominant view in the literature, some evidence also shows that biofuels may have had a reducing effect on food prices in the US during 2011–2017, which supports optimistic views that more food, more energy, and more raw materials can be produced if the land surface is used efficiently (Bilgili et al. 2020).

A study conducted in 2015 revealing aspects of economic analysis of increasing biofuel production on food security also shows that biofuel production may have a negative impact on food security, but at the same time can create opportunities for agricultural development, while the key-factor in promoting promote biofuel programs is price elasticity of feedstock supply (Koizumi 2015).

Maltsoglou I. from the Climate, Biodiversity, Land and Water Department at FAO affirmed in a 2017 interview that there was no clear-cut consensus from experts debate on the relation between biofuels and food prices rise, while biofuel production may be just one from a spectrum of many factors, where the contribution of biofuels ranging from 3 to 75% of the price increase (Maltsoglou 2017).

Durham et al. (2012) demonstrated that removing support for biofuels during a food crop price spike could reduce the magnitude of the spike.

A review of the literature on biofuels and food security conducted by Locke and Henley (2013) found that the published literature does not allow drawing a definite conclusion on the impact of biofuel projects on local food security in developing countries, as the evidence makes difficult to assess this balance; however, an important aspect, beyond the crop itself, is managing land availability, production modeling and project design.

Li et al. (2017) studied whether developing bioenergy will threaten food security in China and concluded that that as long as the right policies are being applied (fiscal policies, subsidies, technological progress, adjustment of food trade) the two are not incompatible, but drew the attention on the fact that the development of bioenergy sector should be tailored to the national circumstances.

Recent research regarding the sustainability of biofuel development in sub-Saharan Africa underline that biofuels produced from energy crops are carbon–neutral and promote the reducing GHG emissions (Jha and Schmidt 2021). The study emphasizes a series of issues that need to be considered when selecting feedstocks for biofuel production, including: the assessment of how biofuel feedstock cultivation affects local or regional socioeconomic conditions, food insecurity and biodiversity; technology constraints, extraction cost. For the sub-Saharan Africa region, appropriate strategies and initiatives are necessary to ensure biofuel sustainability and resilience of the local bioenergy sectors.

A similar study based on data from 51 developing countries concluded that biofuel can positively contribute to food security; initially, biofuels could bring about a competition to food security but in a later stage it can improve food security while sustaining environmental quality (Subramaniam et al. 2020).

A statistical report published by World Bioenergy Association in 2020 underlines that the significant potential to increase the yields in various regions makes agriculture a key sector in harmonizing both food and fuel production, allowing higher global bioenergy use (World Bioenergy Association 2020).

On this topic, in 2015, Jose Graziano da Silva, Director-General of FAO, stated that food vs. fuel is "a false dichotomy" since both options can be reconciled and, furthermore, biofuels can become means of increasing agricultural productivity and food security by providing poor farmers with a sustainable and affordable energy source using flexible policies that stabilize competitive pressures. Also, by making national targets more flexible, mandates for biofuel could be applied over several years, so that a reasonable demand minimize the impact on food prices (da Silva 2015).

Biofuel and food production should not compete and multiple sustainability criteria should be seriously considered when deciding to use biofuels at a large scale. Any step in promoting biofuel industry as one of the renewable energies should be made without sacrificing food security. Since first-generation biofuels are derived from agricultural raw materials that can geopardize food security and land use, they are the most problematic in terms of competing food sources. Thus, the industry should focus on developing next-generation biofuels made from non-food or non-edible vegetal resources, cellulose resources and micro-organisms such as yeasts or algae.

When linking the two aspects—biofuels and food security, *the particular context of the country*—mostly the general state of food security is a factor of great importance (Ghosh et al. 2019). National and local conditions together with the choice of specific technologies and feedstocks determine the potential impact of biofuel policies (HLPE 2013).

In this regard, while developed countries might be able to successfully adapt to necessary changes, poor countries may have to pay a heavy price for shortsighted energy security. Thus, the food vs. fuel debate is very context and country specific, depending on the particular agricultural landscape and the aims pursued by producing biofuels (e.g., entering new agricultural markets or reducing GHGs)—all these determine how biofuels can be optimally integrated into the agricultural production system (Maltsoglou 2017).

Analyzing these approaches and studies results, it is obvious that food security implications of biofuel production are notably complex. The impact on food availability and food commodities prices undoubtedly exists, so all biofuels supposed benefits should be carefully examined against possible negative effects (Ghosh et al. 2019).

4 Food and Fuel: Solutions for Reconciliation

The FAO 2008 Report "The state of food and agriculture in Asia and the Pacific region" suggested since then that government interventions should reduce the potential negative impacts on food security by encouraging only the use of feedstock crops whose production is labor intensive and points out that improved energy security could come at the cost of more food insecurity in countries where the poorest members of society are net food buyers, which could be the case for most other Asian countries (FAO 2008c). That is why FAO recommended at that time that governments offer no special incentives or subsidies for first-generation biofuels production and encourage second-generation biofuels when specific technology becomes commercially viable, and also to reduce environmental impacts or improve the food security of the poor even when biofuel production is competitive. Since then, many countries changed their option (e.g., China initially banned the use of grains for ethanol production), therefore new approaches and strategies are needed to deal with the issue of food-fuel competition.

The 2013 report from the 40th Session of the Committee on World Food Security recommended different types of actions regarding biofuels and food security: "Actions towards enhanced policy coherence for food security and biofuels/ Actions to promote Research and Development (R&D) on biofuels and food security /Actions with regard to linkages between energy and food security" (Committee on World Food Security 2013).

Given the extensive and rising use of biofuels in the last decade, effective solutions should be implemented in bioethanol and biodiesel production, such as (Kurowska et al. 2020):

- using a wider range of non-food raw materials (especially based on cellulose (such as woody biomass, straw from cereal crops from energy crops), and even from algae);
- choosing raw materials from biomass so that its cultivation does not compete with food production;
- diversifying raw materials used for liquid biofuels production;
- using advanced conversion technologies;

- allocation of farmland should prioritize food purposes and distributing the remaining land for cultivation of energy crops.

Adaptive management through systematic monitoring and analysis could be based on several priorities that facilitate the achievement of successful synergies between bioenergy and food security, as follows: "(1) clarifying communications with clear and consistent terms; (2) recognizing that food and bioenergy need not compete for land and, instead, should be integrated to improve resource management; (3) investing in technology, rural extension, and innovations to build capacity and infrastructure; (4) promoting stable prices that incentivize local production; (5) adopting flex crops that can provide food along with other products and services to society; 6) engaging stakeholders to identify and assess specific opportunities for biofuels to improve food security" (Kline et al. 2016).

In order to achieve a "win–win" situation for both sectors, measures may include (Subramaniam et al. 2019):

- redesigning guidelines and policies at national level on both biofuels and agriculture sectors to encourage the development of both sectors;
- improving the crop yields in agriculture sector to respond to an increasing demand;
- expansion of arable land;
- using research & development as a crucial factor in reducing the direct competition between food sectors and biofuel (e.g., by improving seeds' quality, improving biofuels efficiency in terms of resources and processes, explore new technologies for the second and third generations of biofuels).

Yukesh Kannah et al. (2020) studied the potential of food waste—otherwise a serious threat to the environment worldwide—as feedstock for bio-based value-added product recovery, provided that issues such as production processes, pretreatments, the capital cost invested in refining are properly considered. At the same time, all food industry plants processing food and raw materials provide waste suitable for biogas production (Lucian 2016).

A sound approach is to conduct efforts to increase agricultural productivity first, to prioritize meeting future food demand and to direct only the surplus towards biofuels first-generation production (Long et al. 2015; OPEC Fund for International Development 2009).

A suitable choice for environmentally cleaner and economically competitive biofuels would be to produce second-generation biofuels only on land other than cultivated land required for food and feed, which depends on both efficient and effective second-generation conversion technologies and advances in feedstock production and land use regulation (OPEC Fund for International Development 2009).

Another study by Martínez-Jaramillo et al. (2019) on the effects of biofuels on food security applied on Colombia highlighted the importance of integrated models over individual subsystem evaluations regarding food production policies in developing countries. The authors propose an analytical framework as a useful tool for policy makers in order to assess the real potential of biofuel and food security goals and their socio-economic impacts (Martínez-Jaramillo et al. 2019).

Long et al. (2015) highlighted directions, challenges and opportunities that need to be considered in order to equitably meet increasing demands for both energy and food:

- while only a few crops supply the bulk of biofuel and bioenergy production globally, there are other crops that have the potential to become important feedstocks, inducing a positive impact on GHG emissions from the use of fossil fuels;
- new crop development for feedstock production should not lead to unacceptable socioeconomic or environmental consequences, but also delays due to higher standards should be avoided;
- a major aspect for economic viability and biodiversity is increasing the productivity of bioenergy crops per unit land area, as land sparing is considered far more effective than land sharing;
- much of the bioenergy feedstock will have to derive from dedicated production, including investment in forest management and energy tree breeding, as waste and residues from all sectors (post consumption, agriculture, forestry) will not be sufficient to meet rising long-term biomass demand;
- the potential of large-scale microalgae production needs to be more substantiated;
- agronomic research could lead to using marginal land unsuited to food crop production for growing high productivity perennial feedstocks.

FAO's global involvement in supporting countries in developing sustainable bioenergy policies and strategies is made through the Bioenergy and Food Security [BEFS] Approach, aiming to promote food and energy security and contributing to agricultural and rural development (FAO 2021). BEFS Approach specific components offer tools and guidance available for countries depending on the status of their bioenergy policy formulation and implementation and can be implemented by any stakeholder at national, regional and project level.

FAO also promotes Integrated Food-Energy Systems [IFESs], which is a diversified agricultural production farming system that incorporates agrobiodiversity on principles of sustainable production intensification, optimizing land use by combination of food and energy crops and incorporating other sources of renewable energy as a part of the system (FAO 2021).

Studying future challenges and opportunities of the biofuels-food security binomial, Lascano et al. (2016) showed that responsible investment in agriculture that integrate bioenergy into sustainable-development policies and strategies is a prerequisite of fighting hunger and poverty.

As interactions of the water, food, and energy sectors are complex, a broader nexus of these aspects can be associated to sustainable development goals (SDGs) or development indicators and improved management requires two main pillars—improved evidence and improved governance (Smajgl 2021).

5 Analysis of the Biofuels Production and Food Security for the Selected Countries

5.1 Analysis of the Evolution of Renewables Energies

Concerning the five types of energy, i.e., coal, oil, gas, nuclear, and renewable, the analysis of their weight between 2010 and 2019 highlighted that the highest weights in the total energy production in the case of coal were in 2011 (29.69%), 2012 (29.32%), and 2013 (29.27%), for the oil were in 2016 (32.78%), 2015 (32.26%), and 2010 (32.14%), for the gas were in 2019 (23.27%), 2018 (22.75%), and 2017 (22.47%), for the nuclear were in 2010 (5.63%), 2011 (5.14%), and 2019 (4.94%), and for the renewable were in 2019 (13.8%), 2018 (13.7%), and 2017 (13.66%). Conversely, the lowest weights in the total energy production in the case of coal were in 2016 (26.65%), 2017 (26.95%), and 2018 (27.09%), for the oil were in 2019 (30.85%), 2013 (31.56%), and 2018 (31.57%), for the gas were in 2010 (21.22%), 2011 (21.32%), and 2012 (21.43%), for the nuclear were in 2013 (4.81%), 2012 (4.83%), and 2014 (4.84%), and for the renewable were in 2011 (12.22%), 2010 (12.34%), and 2012 (12.53%) (Fig. 1).

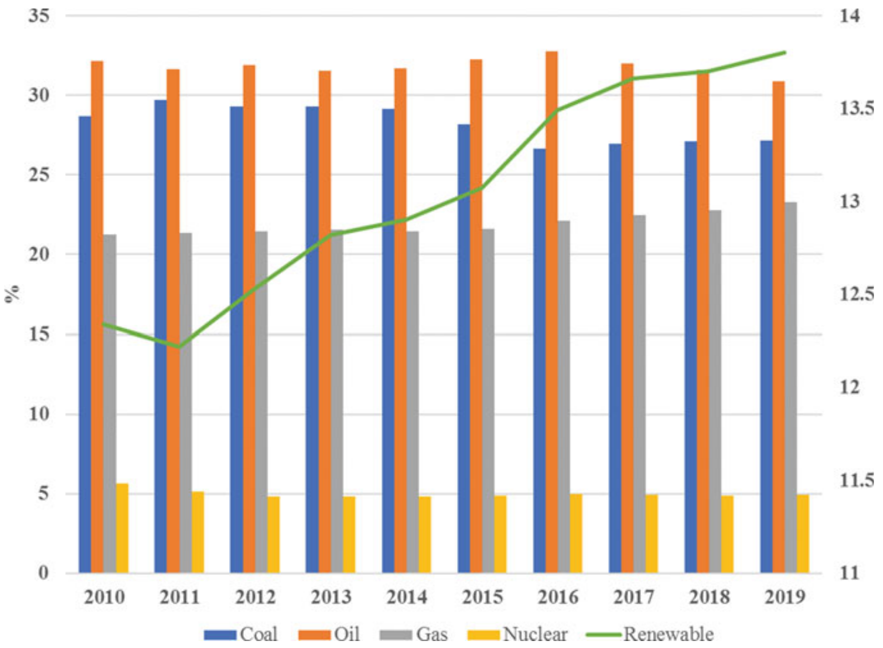

Fig. 1 Weight evolution of world energy production by type of energy between 2010 and 2019. *Source* Authors' own calculation based on data from International Energy Agency (2021b)

As regards the highest increases of each type of energy weight, the following cases can be underlined: coal in 2011 against 2010 (+3.56%), 2017 in contrast to 2016 (+1.13%), and in 2018 versus 2017 (+0.52%); oil in 2015 as compared to 2014 (+1.8%), 2016 against 2015 (+1.51%), and in 2012 versus 2011 (+0.82%); gas in 2019 in contrast to 2018 (+2.29%), 2016 versus 2015 (+2.27%), and 2017 as compared to 2016 (+1.67%); nuclear in 2016 against 2015 (+2.05%), 2019 versus 2018 (+1.02%), and 2015 in contrast to 2014 (+0.83%); renewable in 2016 versus 2015 (+3.21%), 2012 as compared to 2011 (+2.54%), and 2013 in contrast to 2012 (+2.31%). By opposite, the highest decreases of the five types of energy weight were recorded as follows: coal in 2016 against 2015 (–5.43%), 2015 as compared to 2014 (–3.23%), and 2012 versus 2011 (–1.25%); oil in 2017 in contrast to 2016 (–2.38%), in 2019 against 2018 (–2.28%), and 2011 as compared to 2010 (–1.59%); gas only in 2014 versus 2013 (–0.42%); nuclear in 2011 in contrast to 2010 (–8.7%), 2012 against 2011 (–6.03%), and 2017 as compared to 2016 (–1.2%); renewable only in 2011 versus 2010 (–0.97%).

Between 2010 and 2019, there are only two types of energy that recorded continuous increases of their weight, i.e., the renewable energy and the gas excepting 2011 and 2014, respectively.

As for the renewable energy, there are at least 9 types of energy included in this category, such as primary solid biofuels, biogases, liquid biofuels, geothermal, solar thermal, hydro, solar photovoltaic (PV), tide, wave, ocean, and wind. The analysis of their weight between 2010 and 2019 emphasized that highest weights in the total renewable energy production in the case of primary solid biofuels were in 2019 (6.25%), 2018 (6.06%), and 2017 (6.02%), for the biogases were in 2015 (1.51%), 2014 (1.48%), and 2013 (1.45%), for the liquid biofuels were in 2019 and 2015 (0.15%), 2016 (0.14%), and 2014 (0.13%), for the geothermal were in 2010 (1.6%), 2011 (1.56%), and 2012 (1.47%), for the solar thermal were in 2019 (0.19%), 2016 (0.18%), and 2018, 2017 and 2015 (0.17%), for the hydro were in 2010 (83.09%), 2011 (80.57%), and 2012 (78.64%), for the solar PV were in 2019 (9.61%), 2018 (8.23%), and 2017 (6.81%), for the tide, wave, and ocean were between 2013 and 2017 (0.02%), and for the wind were in 2019 (20.15%), 2018 (18.91%), and 2017 (17.94%) (Fig. 2).

On the contrary, the lowest weights in the total renewable energy production in the case of primary solid biofuels were in 2010 (5.25%), 2011 and 2012 (5.26%), and 2013 (5.36%), for the biogases were in 2010 (1.1%), 2011 (1.22%), and 2019 (1.25%), for the liquid biofuels were in 2011 (0.08%), 2012 (0.09%), and 2013 (0.1%), for the geothermal were in 2019 (1.29%), 2018 (1.31%), and 2017 (1.35%), for the solar thermal were in 2010 (0.04%), 2011 (0.06%), and 2012 (0.1%), for the hydro were in 2019 (61.1%), 2018 (63.88%), and 2017 (66.21%), for the solar PV were in 2010 (0.75%), 2011 (1.43%), and 2012 (2.07%), for the tide, wave, and ocean were between 2010 and 2013, in 2018 and 2019 (0.01%), and for the wind were in 2010 (8.04%), 2011 (9.81%), and 2012 (11%).

With respect to the highest growths of each type of renewable energy weight, the following cases can be stressed: primary solid biofuels in 2014 against 2013 (+3.92%), 2016 in contrast to 2015 (+3.33%), and in 2019 versus 2018 (+3.14%);

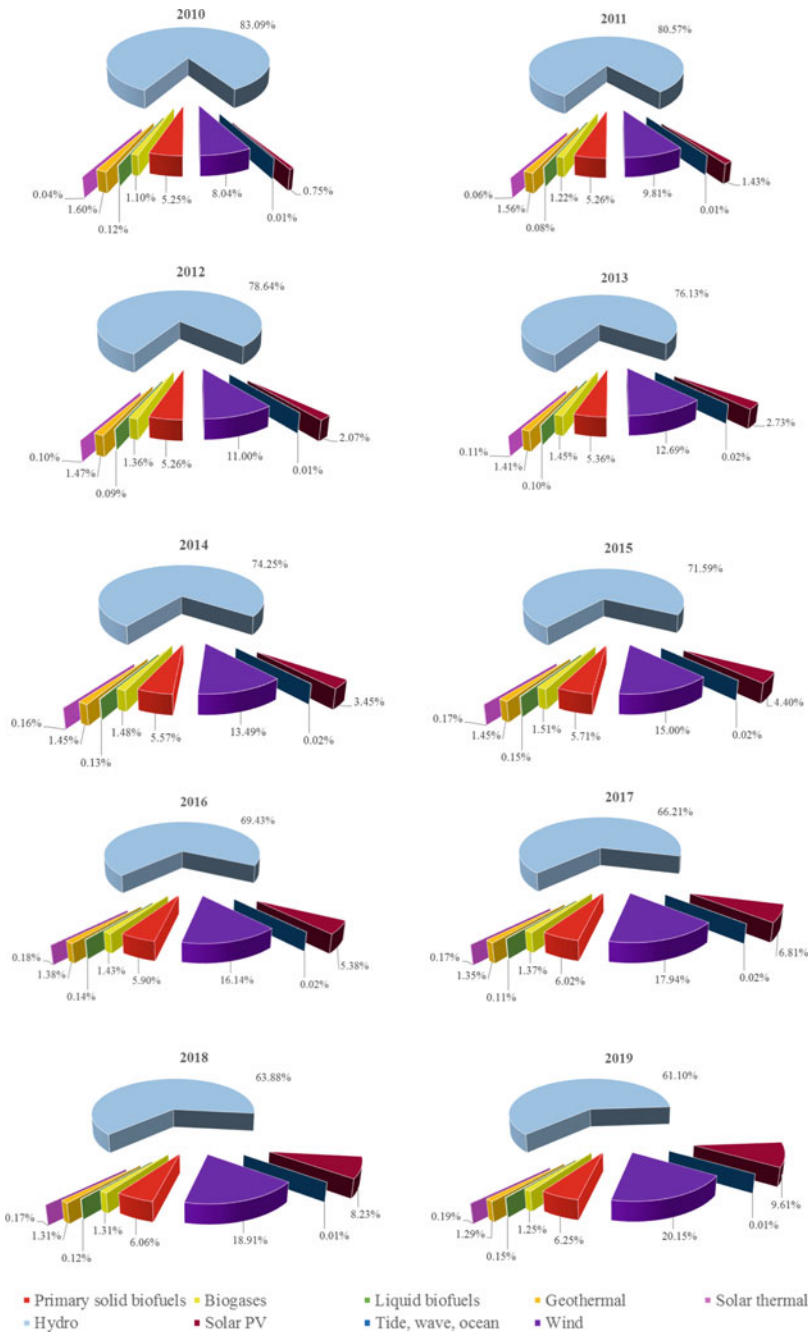

Fig. 2 Weight evolution of world renewables energies production by type of energy between 2010 and 2019. *Source* Authors' own calculation based on data from International Energy Agency (2021b)

biogases in 2012 as compared to 2011 (+11.48%), 2011 against 2010 (+10.91%), and in 2013 versus 2012 (+6.62%); liquid biofuels in 2014 in contrast to 2013 (+30%), 2019 versus 2018 (+25%), and 2015 as compared to 2014 (+15.38%); geothermal only in 2014 against 2013 (+2.84%); solar thermal in 2012 versus 2011 (+66.67%), 2011 as compared to 2010 (+50%), and 2014 in contrast to 2013 (+45.45%); solar PV in 2011 versus 2010 (+90.67%), 2012 against 2011 (+44.76%), and 2013 in contrast to 2012 (+31.88%); tide, wave, and ocean only in 2013 as opposed to 2012 (+100%); wind in 2011 versus 2010 (+22.01%), 2013 in contrast to 2012 (+15.36%), and 2012 against 2011 (+12.13%). The hydro energy was not included in the above group because it has not recorded rises.

Relating to the highest decreases of each type of renewable energy weight, there are only 6 out of 9 types of energy, i.e., the biogases in 2016 against 2014 (–5.3%), 2019 in contrast to 2018 (–4.58%), and in 2018 versus 2017 (–4.38%), the liquid biofuels in 2011 in opposed to 2010 (–33.33%), 2017 as compared to 2016 (–21.43%), and 2016 in contrast to 2015 (–6.67%), the geothermal in 2012 versus 2011 (–5.77%), 2016 in contrast to 2015 (–4.83%), and 2013 against 2012 (–4.08%), the solar thermal only in 2017 versus 2016 (–5.56%), the hydro in 2017 in opposed to 2016 (–4.64%), 2019 as compared to 2018 (–4.35%), and 2015 in contrast to 2014 (–3.58%), and the tide, wave, and ocean only in 2018 as opposed to 2017 (–50%). The primary solid biofuels, the solar PV and the wind energies have not recorded falls during the 2010–2019 period.

The primary solid biofuels, the biogases, the liquid biofuels, the solar thermal, the solar PV, and the wind energies recorded more increases than decreases of their weight between 2010 and 2019. Thus, these are the new renewables energies which will extend their weight in the near future.

5.2 Analysis of the Evolution of Food Security

Concerning the measurement of food security, FAO developed indicators based both on the four traditional dimensions of food security, namely, availability (6 indicators), access (8 indicators), utilization (11 indicators), and stability (6 indicators), and other features of food security (24 indicators). These indicators have been being calculated since year 2000 for 204 world countries (FAO et al. 2021; FAOSTAT 2021).

Considering the large number of indicators, in this chapter only one indicator was selected for analysis, i.e., the prevalence of undernourishment (expressed in percentages), to rank the top 30 world countries with the highest value of this indicator (Fig. 3).

In 2010, the higher levels of the prevalence of undernourishment were in the case of Somalia (75.6%), Haiti (47.5%), Democratic People's Republic of Korea (42.6%), Democratic Republic of the Congo (38.8%), and Congo (36.5%), and the lowest levels were for Eswatini (18.5%), Mongolia (19.1%), Nicaragua (20.1%), Bolivia (20.3%), and Togo (21.2%). In 2011, the top 5 states with the highest levels were Somalia (81.7%), Haiti (46.8%), Democratic People's Republic of Korea (43%),

Fig. 3 The evolution of the prevalence of undernourishment for the top 30 world countries between 2010 and 2019 (%). *Source* Made by authors based on data from FAOSTAT (2021)

Democratic Republic of the Congo (40%), and Iraq (36.7%), while the top 5 countries with the lowest level were Bolivia and Angola (17.2%), Mongolia (18.4%), Nicaragua (19.2%), Togo (19.7%), and Eswatini (20.7%). In 2012, Somalia (79.7%), Haiti (47.7%), Democratic People's Republic of Korea (42.7%), Democratic Republic of the Congo (41.5%), and Iraq (37.1%) recorded the highest values, as opposed to the Solomon Islands (17.1%), Mongolia and Gabon (17.3%), Nicaragua (17.8%), Eswatini (18%), and Togo (19.5%) which registered the lowest values.

In 2013, Somalia (71.3%), Haiti (47.1%), Democratic Republic of the Congo (41.5%), Democratic People's Republic of Korea (41.1%), and Central African Republic (40.3%) recorded the highest values. By contrast, Malawi (16.2%), Bolivia (16.4%), Guatemala (17.6%), Nicaragua (18.1%), and the Solomon Islands (18.8%) registered the lowest values. In 2014, the following states with the highest level can be underlined: Somalia (65.7%), Central African Republic (48.3%), Haiti (46.4%), Democratic Republic of the Congo (40.7%), and Democratic People's Republic of Korea (40.6%). At the opposite end, Cabo Verde (16.4%), Guatemala (17.7%), Ethiopia (17.8%), Djibouti (18.1%), and Côte d'Ivoire (18.6%) recorded the lowest levels. In 2015, the higher levels were for Somalia (60.3%), Central African Republic (49.9%), Haiti (46.1%), Yemen (43.4%), and Democratic People's Republic of Korea (40.3%), and the lowest levels were for Malawi (16%), Côte d'Ivoire (16.5%), Cabo Verde (16.8%), Guatemala (17.3%), and Djibouti (17.5%).

In 2016, Somalia (57.8%), Central African Republic (48.6%), Haiti (46.7%), Yemen (46.1%), and Madagascar (41.6%) reported the highest levels, and Malawi (16.1%), Venezuela and Guatemala (16.4%), Djibouti (16.7%), Cabo Verde (17%), and the Solomon Islands and Nicaragua (18%) registered the lowest levels. In 2017, the higher levels were in the case of Somalia (58.7%), Haiti (48%), Yemen (46.6%), Central African Republic (46.1%), and Democratic People's Republic of Korea (42.9%), and the lowest levels were for Guatemala (16.3%), Djibouti (16.4%), Malawi (16.5%), Cabo Verde (16.7%), and the Solomon Islands and Nicaragua (17.6%). In 2018, Somalia (57.4%), Haiti (47.9%), Central African Republic (46.7%), Yemen (45.4%), and Democratic People's Republic of Korea (42.6%) recorded the highest levels, and Djibouti (16%), Gabon and Cabo Verde (16.2%), Malawi (16.8%), the Solomon Islands (17%), and Nicaragua (18.2%) registered the lowest levels. Finally, in 2019, the following states with the highest level can be underscored: Somalia (59.5%), Central African Republic (48.2%), Haiti (46.8%), Yemen (45.4%), and Madagascar (43.2%). At the opposite end, Djibouti (16.2%), the Solomon Islands (16.5%), Guatemala (16.8%), Malawi and Angola (17.3%), and Nicaragua (19.3%) recorded the lowest levels.

It must be highlighted that Somalia and Haiti were the only states that were in the top 5 countries with the highest level of the prevalence of undernourishment in each of the 10 analyzed years. Other states with numerous ranks in the top 5 were Democratic People's Republic of Korea (in 8 years), Central African Republic (in 7 years), and Democratic Republic of the Congo and Yemen (in 5 years).

The evolution of the prevalence of undernourishment underlined that, in 2011 in contrast to 2010, the highest increases were in the case of Iraq (+16.14%), Gabon (+11.89%), Rwanda (+8.95%), Somalia (+8.07%), and Yemen (+5.68%).

On the contrary, Angola (–29.51%), Sierra Leone (–16.67%), Bolivia (–15.27%), Mozambique (–9.54%), and Chad (–7.44%) registered the highest decreases. In 2012 as compared to 2011, Yemen (+19.35%), Central African Republic (+16.73%), Afghanistan (+14.17%), Kenya (+4.18%), and Democratic Republic of the Congo (+3.75%) recorded the highest rises. The highest declines were in the case of Eswatini (–13.04%), Congo (–8.33%), Nicaragua (–7.29%), Djibouti (–6.31%), and Namibia (–6.03%).

In 2013 against 2012, the highest growths were for Central African Republic (+22.87%), Madagascar (+11.45%), the Solomon Islands (+9.94%), Papua New Guinea (+7.04%), and Mozambique (+6.67%), and the highest reductions were for the Ethiopia (–13.83%), Kenya (–11.24%), Somalia (–10.54%), Namibia (–10.47%), and Timor-Leste (–7.42%). In 2014 versus 2013, the following countries with the highest boosts can be underlined: Central African Republic (+19.85%), Mozambique (+14.73%), Madagascar (+13.6%), Yemen (+12.54%), and Papua New Guinea (+4.39%). The highest decreases were in the case of Ethiopia (–18.35%), Namibia (–10.94%), Côte d'Ivoire (–8.82%), Afghanistan (–7.98%), and Somalia (–7.85%).

In 2015 as opposed to 2014, Lesotho (+43.75%), Mozambique (+15.56%), Yemen (+12.44%), Congo (+9.65%), and Madagascar (+6.91%) recorded the highest increases, and Côte d'Ivoire (–11.29%), Afghanistan (–11.16%), Namibia (–11.02%), Timor-Leste (–8.58%), and Somalia (–8.22%) registered the highest declines. In 2016 in contrast to 2015, highest growths were for Kenya (+7.91%), Yemen (+6.22%), Mozambique (+6.06%), Botswana (+4.92%), and Madagascar (+3.48%), and the highest drops were for Lesotho (–5.35%), Nicaragua (–5.26%), Guatemala (–5.2%), Djibouti (–4.57%), and Somalia (–4.15%).

In 2017 as compared to 2016, the following cases with the highest rises can be underscored: Venezuela (+35.37%), Kenya (+6.03%), Botswana (+4.33%), Democratic People's Republic of Korea (+4.13%), and Afghanistan (+3.6%). The highest falls were for Lesotho (–8.13%), Central African Republic (–5.14%), Nicaragua and the Solomon Islands (–2.22%), Togo (–1.85%), and Djibouti (–1.8%). In 2018 against 2017, Venezuela (+5.41%), Chad (+4.47%), Nicaragua (+3.41%), Liberia (+2.46%), and Botswana (+2.08%) registered the highest growths. On the contrary, the highest reductions occurred in the case of Lesotho (–20%), the Solomon Islands (–3.41%), Cabo Verde (–2.99%), Timor-Leste (–2.92%), and Djibouti (–2.44%). In the end, in 2019 versus 2018, the highest boosts were for Venezuela (+17.09%), Lesotho (+12.98%), Afghanistan (+9.4%), Nicaragua (+6.04%), and Chad (+4.28%), and the highest declines were for Timor-Leste (–3%), the Solomon Islands (–2.94%), Togo (–2.39%), Haiti (–2.3%), and Papua New Guinea (–1.2%).

The analysis of the evolution of the prevalence of undernourishment for the top 30 world countries with the highest level, between 2010 and 2019, underscores that 24 out of 37 states (that came in or out in the top 30 world countries) were in the ranking in each of the 10 years. These countries are as follows: Afghanistan, Botswana, Central African Republic, Chad, Congo, Democratic People's Republic of Korea, Democratic Republic of the Congo, Djibouti, Haiti, Iraq, Kenya, Liberia, Madagascar, Mozambique, Namibia, Nicaragua, Papua New Guinea, Rwanda, Sierra Leone, Somalia, Timor-Leste, Togo, the United Republic of Tanzania, and Yemen.

5.3 Analysis of the Biofuels Production and Food Security

The analysis of the biofuels production and food security was undertaken only for the states that, firstly, were in the top 30 world countries with the highest levels of the prevalence of undernourishment, and, secondly, were producers of biofuels between 2010 and 2019.

The investigation of the International Renewable Energy Agency [IRENA]'s (2021a) database pointed up that only 17 out of 37 states with the highest levels of the prevalence of undernourishment have produced biofuels between 2010 and 2019, i.e., Angola, Bolivia, Eswatini, Ethiopia, Gabon, Guatemala, Kenya, Madagascar, Malawi, Mozambique, Namibia, Nicaragua, Papua New Guinea, Rwanda, Sierra Leone, the Solomon Islands, and the United Republic of Tanzania. The following four subsections will focus on the 2019 top 4 countries of this ranking which both registered the highest levels of the prevalence of undernourishment and obtained only biofuels, namely, Madagascar, Rwanda, Mozambique, and Sierra Leone.

5.3.1 Madagascar

Madagascar is the country with the highest rank of the prevalence of undernourishment and it is also a biofuels producer. Madagascar's entire production consists of biofuels, and it has not been supplying biogas. Madagascar has been using jatropha, sugarcane, oil palm, and oil seeds to make biofuel (GRAIN 2013).

Jatropha (*Jatropha curcas* L.) is a perennial small tree or shrub whose seeds are used to obtain the biofuels (United Nations Conference on Trade and Development [UNCTAD] 2014; United Nations University Institute of Advanced Studies [UNU-IAS] 2012).

A quick glance of the evolution of biofuels weight in both renewable energy production and total energy production showed that it had not exceed 0.09% between 2010 and 2019 (Fig. 4). Madagascar's main energy source has been being the hydro and solar PV energies between 2010 and 2019 with an average weight of 56.38%, except for 2017 (46.74%) and 2019 (49.03%). The weight of fossil fuels recorded an average of 43.56%, excluding the years 2017 (53.2%) and 2019 (50.91%) (International Renewable Energy Agency 2021a).

The level of the prevalence of undernourishment decreased in 2011 as compared to 2010 (–2.41%) and starting with 2012 and ending with 2019 it recorded rises. The highest growth was in the first half of the period (+13.6% in 2014 against 2013). The level of the biofuels weight in renewable energy production registered increases between 2011 and 2013, 2016 and 2017, and in 2019 as compared to previous year (the highest rise of +40% was scored in 2013 as opposed to 2012). The reductions were in 2014, 2015 and 2018 versus previous year (the highest drop of –21.05% was registered in 2018 in contrast to 2017). The level of the biofuels weight in total energy production registered increases in 2012 and 2013 as compared to previous year (the highest value of +73.68% was recorded in 2012 against 2011). The drops were in

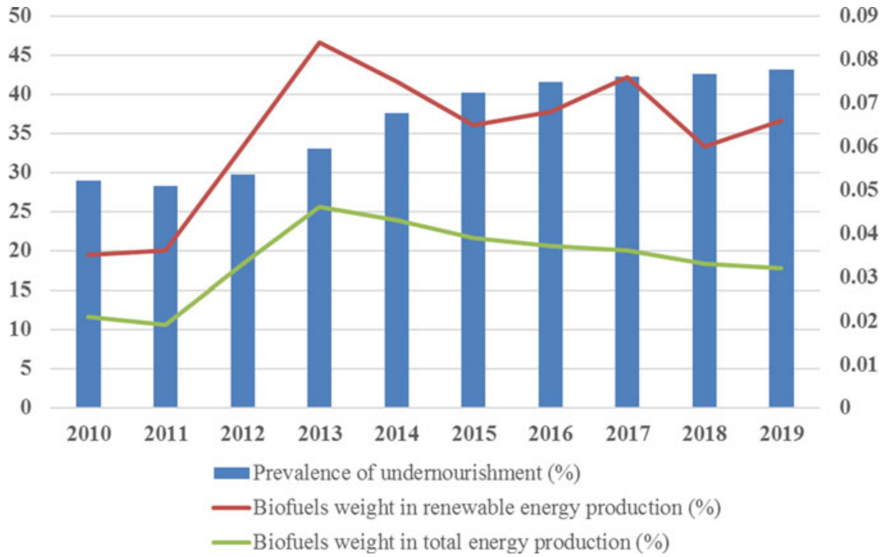

Fig. 4 Evolution of the prevalence of undernourishment and biofuels weight for Madagascar between 2010 and 2019. *Source* Made by authors based on data from FAOSTAT (2021) and International Renewable Energy Agency (2021a)

2011 and between 2014 and 2019 against previous year (the highest fall of –9.52% was recorded in 2011 as opposed to 2010). Hence, the evolution of the prevalence of undernourishment was not correlated neither with the biofuels weight in renewable energy production nor with the biofuels weight in total energy production.

As for the Madagascar's trade energy, the only available data is from 2013 and 2018 when the imports were 25% and 15%, respectively, of the energy supply and there were not exports (International Renewable Energy Agency 2021b).

5.3.2 Rwanda

Rwanda recorded the second highest rank of the prevalence of undernourishment and, similar to Madagascar, it obtains only biofuels, although it has the potential to produce biogas according to Deutsche Gesellschaft für Internationale Zusammenarbeit [GIZ] (2011).

Rwanda has been using the *Jatropha curcas* L. for producing the biofuels (Ntaribi and Paul 2018), but some reports highlighted that it could cultivate other sustainable biofuels crops such as moringa, soya, cassava, sugarcane, and eucalyptus plantations (United Nations Industrial Development Organization [UNIDO] 2015; Deutsche Gesellschaft für Internationale Zusammenarbeit 2011).

The biofuels weight in both renewable energy production and total energy production was low between 2010 and 2019 and it went not above 1.2% (Fig. 5). Rwanda's

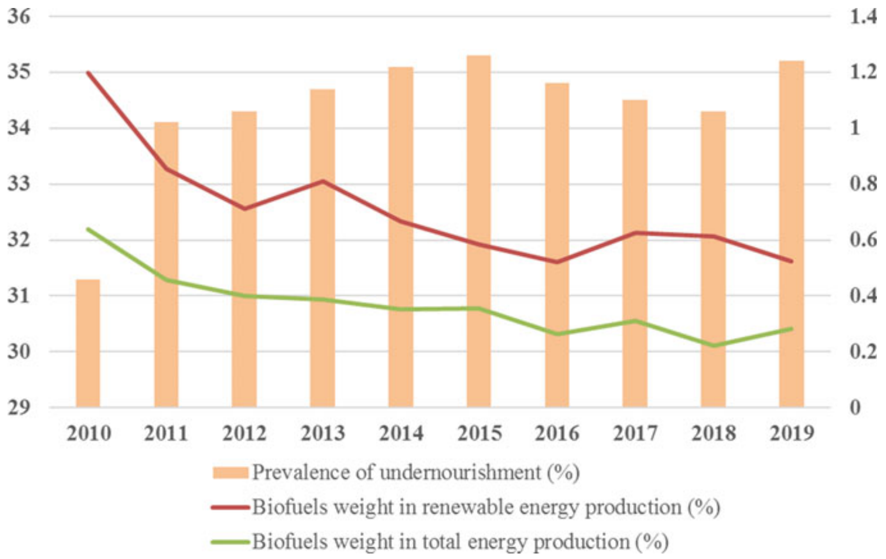

Fig. 5 Evolution of the prevalence of undernourishment and biofuels weight for Rwanda between 2010 and 2019. *Source* Made by authors based on data from FAOSTAT (2021) and International Renewable Energy Agency (2021a)

main energy source has been being the hydro and solar PV energies which maintained relatively constant their weight from 52.65% in 2010 to 53.8% in 2019. The weight of fossil fuels had the same approximately constant evolution from 46.71% in 2010 to 45.91% in 2019 with some increases over 50% in 2013 (52.09%) and 2017 (50.12%) (International Renewable Energy Agency 2021a).

The evolution of Rwanda's prevalence of undernourishment stressed 6 increases between 2011 and 2015, and in 2019 against previous year, and 3 declines between 2016 and 2018 as compared to previous year. The highest rise was in 2011 in contrast to 2010 (+8.95%) and the highest drop was in 2016 versus 2015 (–1.42%). The level of the biofuels weight in renewable energy production recorded growths in 2013 and 2017 as compared to previous year with a peak of +19.92% scored in 2017 against 2016. There were three periods of falls between 2011 and 2012, 2014 and 2016, and 2018 and 2019 as opposed to previous year. The highest reduction was in 2011 in contrast to 2010 (–28.49%). The level of the biofuels weight in total energy production registered boosts in 2015, 2017 and 2019 against previous year (the highest value of +28.05% was scored in 2019 as compared to 2018). Similar to previous indicator, there were three periods of declines, between 2011 and 2014, in 2016 and 2018 as opposed to previous year. The highest reduction of –29.17% was registered in 2018 in contrast to 2017. Thus, the evolution of the prevalence of undernourishment was not linked neither with the biofuels weight in renewable energy production nor with the biofuels weight in total energy production.

In 2013 and 2018, Rwanda imported energy at a weight of 13% and 15%, respectively, of its energy supply, and it has not exported energy (International Renewable Energy Agency 2021c).

5.3.3 Mozambique

Mozambique registered the third highest rank of the prevalence of undernourishment and, similar to Madagascar and Rwanda, it produces only biofuels.

Mozambique has been cultivating jatropha, maize, soybeans, oil seeds, sugarcane, oil palm, and coconut for producing the biofuels (GRAIN 2013; United Nations University Institute of Advanced Studies 2012; Schut et al. 2010). Most of the farmers were not able to obtain jatropha due to lack of productive varieties (at least 3 tons/ha) and agronomic knowledge (Von Maltitz et al. 2016; Slingerland and Schut 2014). Field tests showed that cassava and sweet sorghum are suitable to obtain biofuels in some areas of Mozambique (de Vries et al. 2012).

Between 2010 and 2019, the biofuels weight in both renewable energy production and total energy production has not exceeded 0.45% (Fig. 6). The main energy source for Mozambique has been being hydro and its level declined from 2010 (99.57%) to 2019 (95.02%). The fossil fuels production has recorded a low weight in 2010 and it had a continuous minor increase until 2019, i.e., 0.11% and 4.56%, respectively (International Renewable Energy Agency 2021a).

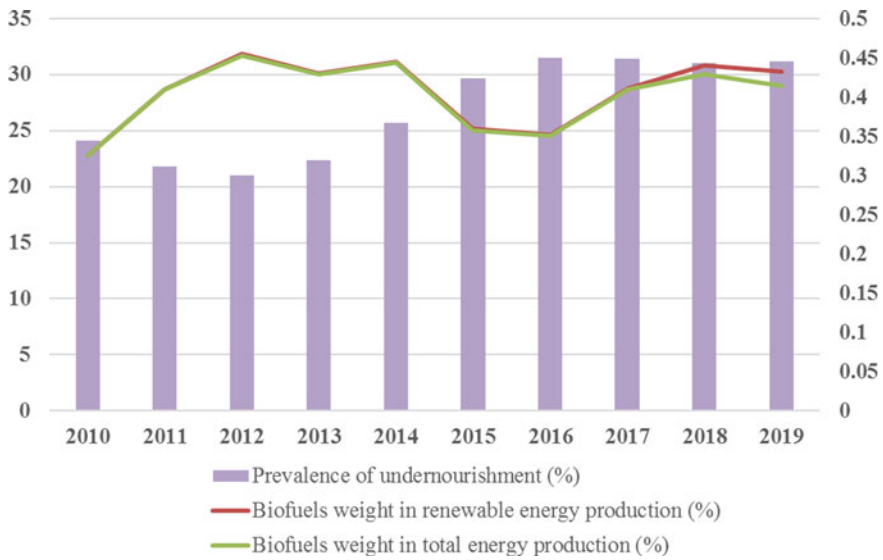

Fig. 6 Evolution of the prevalence of undernourishment and biofuels weight for Mozambique between 2010 and 2019. *Source* Made by authors based on data from FAOSTAT (2021) and International Renewable Energy Agency (2021a)

The evolution analysis of the prevalence of undernourishment underscored that the rises were recorded between 2013 and 2016, and in 2019 against previous year, and the highest increase of +15.56% was scored in 2015 in contrast to 2014. As for the reductions, there were two periods, namely, between 2011 and 2012, and between 2017 and 2018 versus previous year. The highest drop of –9.54% was recorded in 2011 as opposed to 2010.

The evolution of both biofuels weight in renewable energy production and biofuels weight in total energy production were the same considering the number of increases (5 growths) and decreases (4 falls), and the year in which the type of change occurred (the increases were scored between 2011 and 2012, in 2014, and between 2017 and 2018, while the declines were registered in 2013, between 2015 and 2016, and in 2019). The highest boom was recorded in 2011 as compared to 2010 (+27.77%) for both biofuels weight in renewable energy production and biofuels weight in total energy production. The highest decline of –19.10% and –19.37% was registered in 2015 versus 2014 for biofuels weight in renewable energy production and biofuels weight in total energy production, respectively. Between 2011 and 2015 as compared to previous year, the differences among the levels of biofuels weight in renewable energy production and biofuels weight in total energy production were at most 0.5%. Therefore, the evolution of the prevalence of undernourishment was not related neither with the biofuels weight in renewable energy production nor with the biofuels weight in total energy production.

In 2013 and 2018, Mozambique imported energy at a weight of 18% and 23%, respectively, of its energy supply, and it exported energy of 37% and 63%, respectively, of its energy production (International Renewable Energy Agency 2021d).

5.3.4 Sierra Leone

Sierra Leone is the state with the fourth highest rank of the prevalence of undernourishment and it is also a biofuels producer. Sierra Leone has been focusing in producing biofuels, without covering to biogas.

This country has been using jatropha, sugarcane, oil palm, and oil seeds to make biofuel (Popoola et al. 2015; GRAIN 2013) but it also has the proper weather conditions for growing other biofuels crops such as cassava (ECOWAS Regional Centre for Renewable Energy and Energy Efficiency [ECREEE], International Industrial Biotechnology Network [IIBN], UNIDO 2013).

The biofuels weight in both renewable energy production and total energy production was low between 2014 and 2019 and it went not above 2.7% (Fig. 7). Sierra Leone's main energy source was the hydro and its weight decreased from 87.32% in 2010 to 72.53% in 2019, while the fossil fuels weight increased from 12.6% in 2010 to 24.37% in 2019 (International Renewable Energy Agency 2021a).

The evolution of Sierra Leone's prevalence of undernourishment highlighted 5 increases and 4 declines. The rises were recorded between 2012 and 2013, in 2015, 2017, and 2019 against previous year, and the highest increase was in 2013 as

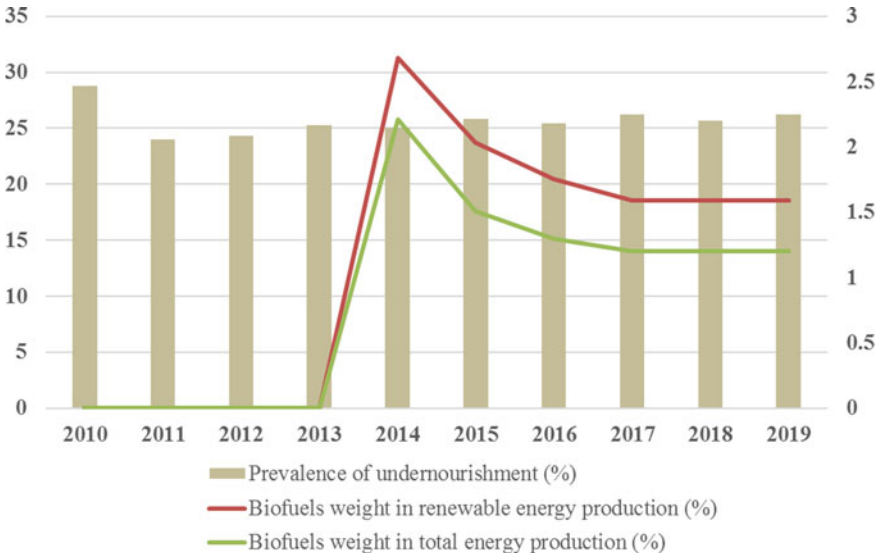

Fig. 7 Evolution of the prevalence of undernourishment and biofuels weight for Sierra Leone between 2010 and 2019. *Source* Made by authors based on data from FAOSTAT (2021) and International Renewable Energy Agency (2021a)

compared to 2012 (+4.12%). The drops were registered in 2011, 2014, 2016, and 2018 as opposed to previous year and the highest fall was in 2011 versus 2010 (–16.67%).

The year 2014 is the first year in which the biofuels production was recorded. Between 2015 and 2018, both biofuels weight in renewable energy production and biofuels weight in total energy production have the same evolution, and their level decreased continuously. The higher fall was registered in 2015 in contrast to 2014, namely, –24.16% and –31.86% for the biofuels weight in renewable energy production and the biofuels weight in total energy production, respectively. In 2019 as opposed to 2018, the level of both biofuels weight in renewable energy production and biofuels weight in total energy production remained unchanged. Thus, the evolution of the prevalence of undernourishment was not connected neither with the biofuels weight in renewable energy production nor with the biofuels weight in total energy production.

In 2013 and 2018, Sierra Leone imported energy at a weight of 22% and 20%, respectively, of its energy supply and it had not exported energy (International Renewable Energy Agency 2021e).

5.3.5 Analysis of the Land Grabbing for Biofuels Production and Food Security

As for the land grabbing issue by the EU and Non-EU companies, it is significant, it expands, and it has consequences such as human rights violation (Directorate-General for External Policies of the Union 2016) and low food security because in numerous cases the farmers' lands from Madagascar, Rwanda, Mozambique, and Sierra Leone have been taken by companies or local authorities to lease or sell them (Yang & He 2021; Bottazzi et al. 2018; Lunstrum 2015; Milgroom 2015; Perrone 2014; Ansoms 2013; Franchi et al. 2013; GRAIN 2013; Lagerkvist 2013; Borras et al. 2011). In some published papers, reports and books, this issue is totally neglected (Neimark 2013; Olanya 2012; Matondi et al. 2011; Cotula et al. 2009).

Based on Land Matrix's database, an Italian company was engaged in a land deal to lease 19,000 ha for growing jatropha in Madagascar to produce biofuels. In 2020, only 2,000 ha were planted, and the company was looking to sell the operation due to bad quality of the plantation (Land Matrix 2020a).

In Mozambique, there were five land deals. The first land deal was a purchase of 21,000 ha for raising jatropha in two different towns by an association of two private companies from Canada and Kenya, but in 2010 the area was abandoned (Land Matrix 2020b). The second land deal was a lease in 2010 of 10,000 ha for plating cassava and jatropha by a South Africa company and there is no information about the present status of this investment (Land Matrix 2020c). The third land deal was signed in 2010 for cultivating jatropha on 10,000 ha by a Portugal company. In 2020 there were only 200 ha planted with sugarcane since the owner of the area was changed in 2013 (Land Matrix 2020d). The fourth land deal was signed in 2010 for cultivating jatropha on 5,670 ha by a United States of America company and it has stopped in 2013 (Land Matrix 2020e). The fifth land deal was a lease which was signed in 2010 and it started in 2011 for planting jatropha and sunflower on 6,300 ha by a group of two Italian companies. This projected was abandoned in 2013 because it was discovered that the soil is not suitable for agriculture due to high salinization (Land Matrix 2020f). There were not engaged land deals in Rwanda and Sierra Leone between 2010 and 2019 according to Land Matrix (2020g).

Data provided by the Land Matrix is incomplete, even if is updated to 2020, because although, firstly, most of the companies that have signed land deals in Madagascar and Mozambique have abandoned the production at the least in 2013, and, secondly, Rwanda and Sierra Leone have not undertaken land deals, all these four countries reported biofuels production according to the International Renewable Energy Agency's database. Thus, most probably, information for the majority of the land deal projects has not been being shared to the public for various reasons.

6 Conclusions

Current growing issues such as: greenhouse gas emissions, energy dependency and supply insecurity urged the need for another approach which led to increasing the use of biofuels (Ajanovic 2011). Given that, nowadays, scientists are looking for different energy sources as alternatives to the non-renewable energy sources, priority is obviously given to sources that cause minimal impact to the environment and the society.

Biofuel sector is an economic reality which has both global and local effects, positive and negative, short and long term, and presently should be oriented to biofuels development so as to limit their potential negative impacts and strengthen their potential positive impacts, which requires international coordination of policies (HLPE 2013), while particular contexts should be managed at local level.

All biofuels used to achieve the EU's targets should meet the criteria of sustainable development and reduced GHG emission and the production of agricultural raw materials should not threaten food security and biological diversity (Kurowska et al. 2020).

The conflict between biofuel and food security, although a justified concern, could be reconciled if environmental quality remains a permanent main objective while food supply is not compromised. To this end, mostly in developing countries (Subramaniam et al. 2020), governments should design and implement policies promoting biofuels which are consistent with both environmental sustainability and food production: improving sustainable agricultural practices, incentives for the development process, financial support for using environmental friendly technologies, involving multinational corporations into specific projects, promoting development of new generations of biofuels which do not compete with food production while preserving the environment.

The coal and nuclear production recorded the highest weight in the total energy production in the first half of 2010–2019 period, in contrast to the oil, gas, and renewable production which registered the highest weight in the total energy production in the second half of the same period. By opposed, the coal and nuclear production recorded the lowest weight in the total energy production in the second half of 2010–2019 period and the oil, gas, and renewable production registered the lowest weight in the total energy production in the first half of the same period.

Between 2010 and 2019, the weight level of coal, oil and nuclear recorded 4 increases and 5 decreases as compared to gas and renewable which registered 8 increases and one decrease. It is solid evidence that the renewable energy has risen its weight in the last 10 years, but it will not be able to replace the non-renewable energies in the following 20 years since the gas, for instance, recorded a higher weight (23.37% in 2019 in contrast with 13.8% for renewable energy) and the growth rate of the gas is higher (2.29% in 2019 against 2018) than the renewable energy (0.73% for the same period).

The biogases, geothermal, and hydro energies registered the highest weight in the total renewable energy production in the first half of 2010–2019 period, in contrast to the primary solid biofuels, liquid biofuels, solar thermal, solar PV, and wind which recorded the highest weight in the total energy production in the second half of the same period. By opposite, the geothermal and hydro energies registered the lowest weight in the total renewable energy production in the second half of 2010–2019 period, and the primary solid biofuels, biogases, liquid biofuels, solar thermal, and wind energies recorded the lowest weight in the total renewable energy production in the first half of the same period. Thus, the biogases recorded both the highest and lowest weight in the first half of 2010–2019. A particular case is the tide, wave, and ocean energy because the weight recorded was either 0.01% or 0.02%. Furthermore, the highest value (0.02%) was scattered between 2013 and 2017 (at the near years of the first and second half of the analyzed period), and the lowest value (0.01%) was distributed between 2010 and 2012, and 2018 and 2019 (at the beginning and ending years of the analyzed period).

The analysis of the evolution of renewables energies weight showed that there are five cluster energy categories. The first category comprises the energies that recorded a continuous increase of their weight in each year between 2010 and 2019, such as the primary solid biofuels, solar PV, and wind. The second category includes the renewable energies that registered more increases than decreases, i.e., the solar thermal (7 increases and 1 decrease), the liquid biofuels (6 rises and 3 falls), and the biogases (5 boosts and 4 drops). The third category consists of energies that recorded a continuous decline of their weight in each year between 2010 and 2019 and it is the case of the hydro. The fourth category contains the energies that registered more reductions than growths, e.g., geothermal (7 reductions and 1 increase). The last category takes in the energies that recorded and equal number of increases and declines such as the tide, wave, ocean energy that registered one rise and one fall.

Even if Somalia, Haiti, and Democratic People's Republic of Korea had the highest level of the prevalence of undernourishment between 2010 and 2019, they have recorded more decreases (6 falls) than increases (3 rises) due to the major differences of their level as compared to other countries. It is worthy to notice that since Venezuela entered in the top 30 countries in 2016 (place 29), it had a continuous and significant increase of its level in 2017, 2018, and 2019 against previous year (35.37%, 5.41%, and 17.09%, respectively) which equates to places 22, 20, and 15, respectively, in the ranking.

The countries with the most numerous and highest level of rises were Madagascar (8 growths of which 4 were major), Yemen (7 rises of which 5 were significant), Central African Republic and Afghanistan (6 boosts of which 3 were important). This explains the fact that Madagascar, Central African Republic, and Yemen, which had a rank at the middle of the top 30 countries in 2011 (places 13, 14, and 16, respectively), went up in the top 5 countries in 2019 (places 5, 2, and 4, respectively). By opposite, the countries with the most numerous and highest level of declines were Namibia and Timor-Leste (9 falls of which 4 were major), Djibouti (8 reductions of which 4 were important), and the Solomon Islands (5 drops of which 3 were significant). This makes clear that the Namibia's and Timor-Leste's rank, which were in the first half of the top 30 countries between 2010 and 2014, moved to the second half of the top 30 countries between 2015 and 2019.

In view of the evolution of both prevalence of undernourishment and biofuels weight in renewable energy production and in total energy production for Madagascar, Rwanda, Mozambique, and Sierra Leone, between 2010 and 2019, based on data from the International Renewable Energy Agency, the population's food security of these countries has not been compromised by biofuels production. Furthermore, data analyzed from the Land Matrix have not underlined cases of low food security due to land grabbing through the land deals, although there were reported numerous events by other surveys which leads us to state that in those situations the population's food security was jeopardized.

The limitations of this research relate to the lack of annual data available for Madagascar, Rwanda, Mozambique, and Sierra Leone concerning the land surface cultivated with feedstock used to produce biofuels, the weight of area harvested with crops that are both edible for human consumption and used to obtain biofuels, the exports and imports quantities of biofuels, and the active land deals signed for producing biofuels.

It is clear that the links between bioenergy and food security are very complex and can only be addressed by an integrated approach which promotes both and ensures bioenergy contribution to sustainable development.

As biofuels production implications are very complex and affect different sectors, future researchers shall continue to thoroughly analyze the energy-water-food nexus. It seems that more studies are needed in order to establish the coordinates of the food vs. fuel competition, while both supporters and opponents of biofuels acknowledge the serious impact on the global food production.

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Exploring the Relationship Among Economic Growth, Energy Consumption, Carbon Emission and Trade: A Panel Vector Error Correction Model (VECM) Analyses

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Abstract This study empirically examines the causality among economic growth, energy consumption, carbon emission and trade in Argentina, China, Ghana and India from the balanced dataset of 1990–2017. Using the Panel Vector Error Correction Model with the panel data we examine the long run and short run causality among the variables. The result of this study shows that long run relationship exists between the variables. The finding suggests that, promotion of an alternative energy sources like clean energy (renewable energy) is recommended that reduces carbon emission without hampering economic growth and trade.

Keywords Economic growth · Carbon emission · Trade · Renewable energy · Panel VECM

1 Introduction

Economic growth and energy consumption is widely explored scientifically in developed and developing countries (Apergis and Payne 2010; Belke et al. 2011; Ucan et al. 2014; Azam et al. 2015; Bhattacharya et al. 2016; Ito 2017; Gozgor et al. 2018; Shahbaz et al. 2018; Le et al. 2020). Energy consumption ensures economic growth and economic growth require energy consumption as well, thus both tend to have an interdependent effect. Moreover, Economic growth leads to trade facilitation (Hossain 2011; Shahbaz et al. 2013; Sebri and Ben-Salha 2014; Destek and Sinha 2020) both in the form of export and import. Exporting countries raise their production to stabilize in the international market that demand more energy to consume. Such demand is fulfilled either by self-sufficiency in energy resources or to import. Further, oil exporting countries produce more energy resources to continue trade. In both the scenarios, either export or import, energy is used in the form of fossil fuel

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for their requirement and it greatly causes carbon emission. Burning of fossil fuels in the domestic production, and its trade consumes significant energy. Exporting countries sells more fossil fuels to generate income and oil exploration in the absent of efficient technology causes carbon emission. Thus, there is a strong association between the economic growth and carbon emission and energy consumption with trade. The objective of this study is to empirically examine the causality among economic growth, energy consumption, carbon emission and trade in Argentina, China, Ghana and India from the balanced dataset of 1990–2017 through Vector Error Correction.

The novelty of this study is to examine the combined effect of energy consumption, economic growth and trade on carbon emission in Argentina, China, India and Ghana. Further, this study uses panel VECM model which has not applied before for the mentioned country case for the mentioned years. Thus, study significantly adds value to the existing literature.

This paper is organised as follows: Sect. 2 summarised literature review; Sect. 3 present methodology and result. Section 4 provides discussion and policy and Sect. 5 concludes the paper.

2 Literature Review

The relationship between energy consumption, economic growth, carbon emission and trade has been studied by several researcher in the different country.

A global study by Sharif et al. (2019) empirically examined the causal relationship between energy consumption and carbon emission in seventy-four nations in the period of 1990–2015. By the application of panel estimation, their result shows long run cointegration among the variables. It has been found that non-renewable energy consumption increases carbon emission and environmental degradation, whereas, renewable energy consumption reduces the environmental effect. The author has recommended that to deal with the environmental problem that arises from the non-renewable energy consumption, government of respected countries could reduce the uses of non-renewable energy consumption and increases the share of renewable energy in all the sector. Moreover, to achieved the target of sustainable development, the energy policies could be taken and take possible step towards the commencement of proper strategies in the form of micro finance in the clean energy projects.

Further study by Acheampong (2018) used panel VAR model to check the association between energy consumption, economic growth and carbon emission with the use of 1990–2014 data set for the 116 countries over the world. The result of their analyses differs at the global level, but there are some associations among the variables existed. The introduction of trade openness could influence energy consumption and carbon emission at the global level which may be reduced with the technological transfer with trade liberalization policies that ultimately help to conserve energy and environment. However, some limitation arises with the application of these recommendation at the individual level but structural policies should be implanted at both the global and regional level.

AL-Mulali et al. (2013) study empirically examined the association between energy consumption, CO_2 emission and economic growth in the Latin American and the Caribbean countries by using the data on 1990–2008. With the application of time series model (Canonical Cointegrating Regression (CCR) Test), it was found that bidirectional relationship exist among the variables in the long run. The finding suggest that these countries should reduce the wastage of energy in by energy conservation and enhance the share of green energy by with the application of efficiency measures.

Similarly, Koengkan and Fuinhas (2020) study examined the linkage between co_2 emission and its determinants which includes economic growth, trade openness, renewable energy and urbanisation in the Latin American and Caribian countries by using the panel data of 1990–2014. With the application of Panel ARDL model, their result shows a positive association between the variables in the short run (except urbanisation) and long term. Economic growth and trade uses fossil fuels for energy requirement that lead to emission. As opposite to this, the uses of renewable energy mitigate emission and environmental degradation in the both short and long term. However, such transition seems to be low due to climatic condition and existing dependence of fossil fuel power plants for the energy requirements. In order to reduce the emission, concerned countries could increase the technology and energy efficiency measure by importing energy efficient technologies for the production and consumption of energy efficient appliances. To increase the pace of energy transition and emission consideration, policy measures for the financial requirement is recommended which meets the infrastructure investment requirement for the development of renewable energy technologies in the respected countries.

Jamel and Maktouf (2017) examined the association between economic growth, financial development, trade openness and CO_2 emission in the European countries by using the panel data from 198 to 2014. Their key finding shows that economic growth and co_2 emission is positively related. Further, GDP influence trade openness indirectly via financial development which is slightly different from their earlier findings. This motivates policy makers to use energy production and prevention policies. Such steps requires political willingness for initiating the common objective and purpose with different strategy design for each member states.

Lv and Xu (2019) study examined the co_2 emission with trade openness and urbanisation in the fifty five middle income countries by using the panel data of 1992–2012. The result from Panel ARDL approach reveals that the variables have both short term and long term relationship. The influence on economic growth is on the trade and urbanisation. Further, Trade openness have more impact on the long term than short term in the environment in the form of carbon emission. Further, urbanisation is also influenced by economic growth which impact in the long run is greater than short run. Such finding suggests that trade liberalisation policies could be a possible way to reduce the impact of trade openness on the carbon emission and their respected impact on socio economic development.

Afridi et al. (2019) extended the study in SAARC region by checking the existence between per capita income, trade openness, urbanisation energy consumption and carbon emission from 1980 to 2016. By applying the GLS estimator method, their finding shows the association among the variables. Trade activities influences CO_2 emission due to industrial energy uses. Further, higher economic activities in the large countries influences more energy consumption that enhances environmental degradation in the form of deforestation and urbanisation. Thus, clean energy technologies and renewable energy sources are recommended that could be possible with positive policy implication to combat the impact of CO_2 emission in the SAARC region.

In case of EU-28 countries, Balsalobre-Lorente and Leitao (2020) extended the study with the inclusion of tourism with trade, carbon emission and renewable energy to check the linkage with economic growth in the period of 1995–2014. By the application of panel fully modified least squares (FMOLS) and panel dynamic least squares (DOLS) the result shows the linkage between all the variables either unidirectionally or bidirectionally. Such co-existence suggest that EU countries have to focus on the infrastructure development that promotes economic growth along with trade, clean energy sources and reduce the carbon emission. The primary focus is on budget allocation for the investment in renewable energy sources within the economy which could likely protect natural and socio—cultural resources that boosts trade, tourism and economic growth with a sustainable manner.

Similar study is extended with EU-40 countries by Jamel and Maktouf (2017) with the inclusion of financial data in 1985–2014 with the use of OLS estimator. The key finding of paper shows that the bidirectional relationship exists between economic growth to financial development and carbon emission, and carbon emission to trade liberalization. Author suggest that energy production and preservation policies could be the focus area of EU countries to manage their economic growth along with environmental qualities that could be possible with a positive political will.

Bento and Moutinho (2016) study applied ARDL approach to examine the association between electricity production, economic growth, international trade and carbon emission in 1960–2001 for Italian economy. Their result shows that all the variables are related with each other both in the short run and long run. Such existence proved the author predetermined hypotheses related to GDP growth, international trade and electricity production with carbon emission. These finding helps to draw the key conclusion about the environmental pollution which is likely to reduce with the production of renewable electricity. Although, such recommendation is prior set by the action plan of the Italian government in the energy supply in the economy which is further intensify with the provision of incentive policy such as, tariff, green certificates etc. Such steps smoothen the production and uses of renewable energy with the energy efficiency parameter.

Phuc Nguyen et al. (2020) study shows the influences of economic integration in the form for financial inflows and trade openness to carbon emission for 33 emerging economies in the period of 1996–2014. The finding of this study shows positive influence of financial inflows both in short run and long and whereas trade openness causes carbon emission in the short run only. Such finding ensures that once trade matures, policy measure like, trade liberalization help to adopt environmental standards for the industries and continuous learning process helps to reduce carbon emission in the emerging economies.

Attiaoui et al. (2017) study examined the causality among economic growth, renewable energy consumption and carbon emission in African countries in 1990–2011. The result shows that all the variables have linkage with each other both in the short run and long run. Non-renewable energy and economic growth promotes co_2 emission whereas renewable energy use helps to reduce reduces it. Such finding suggest that African countries promotes investment in renewable energy that will benefits both economic growth and reduces energy dependency.

Chen et al. (2019) study examines the linkage between economic growth, energy consumption, trade and co_2 emission in China by using the data set of 1980–2014. With the application of ARDL and Panel VECM model, their result explored that all the variables have both short and long run association. The key finding of this study shows carbon emission is positively related to the mentioned variables which is considerable point of Chine. In the light of this, authors have recommended some policy measure for reduction of co_2 emission which includes financial and legal support for the development, production and utilization of renewable energy, its uses in the industries and technology transfer to improve renewable energy technology in China.

Khan et al. (2020) analysed the relationship among international trade and carbon emission in G-7 countries in the period of 1990–2017. The results confirm a stable long-run relationship among CO_2 emissions, trade, income, environmental innovation and renewable energy consumption. There is a positive relationship between GDP and import and, negative relationship exists between export and renewable energy consumption to carbon emission. Such finding helps to draws some important policy consideration in regard to eco-friendly measure, innovation in the renewable energy technologies and its uses. Moreover, tax imposition on the imported goods is a measure to generate revenue for the investment requirement in the environmental related policy achieve sustainable development for G7 countries.

Rasoulinezhad and Saboori (2018) examined the relationship between macroeconomic variables and carbon emission in the Commonwealth of independent states in the period of 1995–2015 by using the panel DOLS and FMOLS methods. Their result shows bidirectional relationship in the long run among the variables. Non renewable energy sources and primarily fossil fuels contribute directly in the economic growth and carbon emission as compare to the uses and consumption of renewable energy sources in these countries. Moreover, economic growth and trade openness causes co_2 emission in the short run. On the basis of such findings, author recommends that incorporation of macroeconomic policies, foreign trade strategies and environmental concern in the development plan is considerable to mitigate carbon emission without compromising the economic growth of commonwealth of independent states. Dogan and Seker (2016) empirically explored the relationship between energy consumption, output, trade and financial development on the carbon emission in the period of 1985–2015 in the top renewable energy consuming countries. By using the FMOLS and DOLS estimator, results indicated that all variables influence carbon emission in the long term. The finding also indicated that high income countries uses renewable energy and reduced carbon emission due to environmental measure adoption which is not true in case of low income countries. Further, trade openness leads to decrease carbon emission in top renewable energy consuming countries. Such finding recommended that to mitigate the problem of co_2 emission, renewable energy uses increased by the countries with policy measures and by adopting environmentally friendly technology to maintain sustainable economic development.

Further, this study extended with the inclusion of urbanization in USA (Dogan and Turkekul 2016) for the period 1960–2010. By using ARDL approach, findings indicated that all the variables are related to each other. Energy consumption is the prime reason for co_2 emission and efficient energy policies possibly reduce carbon emission. Kasman and Duman (2015) explored the study in EU member and candidates countries in the period of 1990–2010. By using FMOLS, result indicated that economic growth, energy consumption, trade and urbanisation are the key determinant of CO_2 emission. Such findings recommends that policymakers in the respective countries required energy policies such as reduction of energy intensity and increase the share of clean energy sources along with energy efficiency to protect the environment.

Ertugrul et al. (2016) extended the study in top ten developing country to examine the causality among economic growth, energy consumption and trade on carbon emission in the period of 1971–2011. Using the ARDL approach, their finding indicated that long run association exist among the variables in most of the country. Thailand, Turkey, India, Brazil, China, Indonesia and Korea are top emitter. In addition, trade openness increases carbon emission more in case of Turkey, India, China and Indonesia than other countries. Such findings recommended policy measures for developing country, such as use of clean and environmentally friendly technologies in the production process without hampering the economic growth. Further, energy efficiency in the production could be accelerated through financial support in the scientific institution and research project.

Ahmed et al. (2017) study examined the determinants of carbon emission in Five South Asian countries in the period of 1971–2013. Finding from FMOLS methods indicated that energy consumption, income, trade openness and population are associated with each other in the long run that causes carbon emission. These variables are either related to unidirectionally or bidirectionally through carbon emission. Such findings advocated that co-operative behaviour of South Asian countries make it possible to combat the environmental emission through immediate response on energy policy for general agreement in carbon reduction measures to promote sustainable development in the region.

Whereas, Gulistan et al. (2020) study examined the carbon emission and its determinant in the 112 countries in the period of 1995–2017 through GLS method. The result indicated that economic growth, energy consumption and trade are associated to carbon emission. Further, Energy consumption which is supported by trade and tourism is significantly boost carbon emission because the high uses of fossil fuel, oil and non-renewable sources of energy. Upper and high-income countries contributed more environmental degradation than lower income countries. Such finding recommended that co-operative policy measures required to mitigate the emission problem. In addition, high income regions have to adopt environmentally friendly measure whereas, low-income countries should tighten their trade liberalization policies. Further, green energy projects should be promoted through investment and government policies. In addition, such motivation is possible through the active participation and awareness campaign of NGOs and government in the regions.

Cetin et al. (2018) examined the carbon emission through energy consumption, economic growth, trade and financial development in Turkey by using the annual time series data of 1960–2013. The empirical result from ARDL approach reveals that economic growth, energy consumption and trade are key determinant of carbon emission in the long run. Higher economic growth and export intensive industries required more energy consumption that leads to carbon emission in significant amount. Further, based on these findings, authors have recommended the requirement of policy measure to reduce carbon emission without compromising the economic growth which is experienced higher in Turkey. Such measure includes the application of trade subsidies and taxes in the energy intensive and high polluting industries. Further, the uses of clean energy sources such as solar, wind, biodiesel etc. should be promoted via clean energy and environmentally friendly technology and credit facilities in the Turkey.

Dong et al. (2018) study examined carbon emission, economic growth, renewable energy consumption in case of 128 countries categorised by region and location by using the data of 1990–2014. The empirical finding of this study shows that carbon emission increased by economic growth and reduced by the use of renewable energy. The finding advocated that as economic growth is energy intensive, an economic transition in renewable energy (increase the share of renewable energy in energy mix) play a key role to mitigate carbon emission in the respected countries except from their difference on the income and regional level. Farhani and Ozturk (2015) study examined the relationship between real GDP, energy consumption, carbon emission, trade and financial development in Tunisia by using the data of 1971–2012. By using the ARDL approach finding indicates long-run relationship between variables. Such findings advocated some policy measure to develop alternative energy sources (clean energy sources) and increase the energy efficiency. Further, the adoption of energy conservation policies control energy demand for trade and population of Tunisia.

Also, Zhang et al. (2017) study examined the determinant of carbon emission in Ten Newly Industrialised countries in the period of 1971–2013. The panel estimation method shows the economic growth, energy consumption, international trade results carbon emission in the respected country both short and long run. International trade promotes energy consumption immediately and increase carbon emission whereas, trade openness mitigates carbon emission due to technology transfer and reduction of excess capacity. The finding recommends that countries have to reduce fossil fuel consumption and replaced it with the renewable energy. This could be achieved through increase investment in the energy purification technology and renewable energy. Further, more fund required to mobilised in the environmental protection measure.

In the case of Sub-Saharan African countries, Zerbo (2017) study shows that for a labour abundant and oil producing countries, the focus is to promote trade and income generation with one hand and reduce carbon emission with the adoption of energy efficiency measure in another hand. In similar country case, Esso and Keho (2016) empirically examined the exitance of a positive relationship from energy consumption to economic growth and carbon emission. To tackle the problem of carbon emission in the economic growth, investment is recommended in the development of new energies with suitable infrastructure.

Further, Lawal et al. (2020) study shows a positive association between electricity consumption and economic growth in African countries with a particular level of energy uses at a threshold level. Instead of focusing on it, attention required on education, health and trade which is influenced by economic growth. Another study on African countries by Ackah (2015) shows that energy consumption, productivity and economic growth are related both in the long and short term. Clean energy are required to be developed as a commercial energy in the place of traditional sources of energy. This can be implemented through investment in energy efficiency measures along with the implementation of effective energy policies.

Additionally, a study by Boateng (2020) shows that economic growth and trade are positively related to carbon emission in Ghana with different intensity levels. Wang et al. (2019) concludes that for 186 countries, the relationship between energy consumption, economic growth, prices and urbanisation exists instead of different income level. For excessive uses of energy consuming countries require to adopt energy conserving measure for the long term. A study by Saidi and Hammami (2015) examined a positive relationship between energy consumption and carbon emission in 58 countries. Economic growth and energy consumption shows a strong and positive relationship within the countries. Such variables also act complementary to each other. Antonakakis et al. (2017) study shows that for 106 countries, energy consumption and carbon mission are positive whereas, energy consumption and economic growth are bidirectional. Further, economic growth results greenhouse gas emission. The heterogeneous nature of energy consumption in different countries required the need to promote clean energy production.

In the case of 102 countries, Le et al. (2020) study shows that energy consumption and economic growth are related to each other. Non- renewable energy consumption contributes to higher carbon emission, that could be controlled through the production and use of renewable energy in the long run. Moreover, the promotion of renewable energy consumption can lead to economic development as well. These promotions through the governmental support can expand the entrepreneurial activities in the clean energy sector, that can further lead to higher economic growth through enhanced money circulation in the sector. Maji et al. (2019) study shows that in West African countries, renewable energy affects economic growth more than non- renewable energy (wood biomass). Author recommends that the promotion of clean energy is possible to adopt clean energy technologies.

The Panel Vector Error Correction Model (PVECM) is widely used by the researcher to measure causal relationship with the panel data for a long period of time. This model enables us to check the endogeneity between the variables that is expected to be happen in the long run. Besides, PVECM manage the cointegration and causal relationship between the variables.

3 Methodology and Results

3.1 Data

This paper uses annual balanced panel data set of Argentina, China, India and Ghana over the years of 1990–2017. All data are extracted from World Development Indicators of World bank. Our study uses energy consumption (equivalate of oil), gross domestic product (Constant 2010 US $), carbon emission (metric ton per capita) and Trade (percent of GDP). For empirically analysing, the data cleaning procedures were adopted. Figure 1 represent conceptual hypothetical framework of the study. At few points, the unavailable data was computed by taking an average of last three years assuming that there is no significant change for the computed year. Due to the large digits, the data was converted into log form for analyses.

To examine the causal relationship between the energy consumption, carbon emission, economic growth, and trade, the following function was used:

$$\mathrm{CEM} = f\,(\mathrm{ENR},\ \mathrm{GDP},\ \mathrm{TRD}) \tag{1}$$

where, CEM is carbon dioxide emission, ENR is energy consumption, GDP is gross domestic product and TRD is trade.

A three-stage procedure is adopted in this study. In the first stage, we computed unit root test for data to check their stationarity level. In the second stage, we did

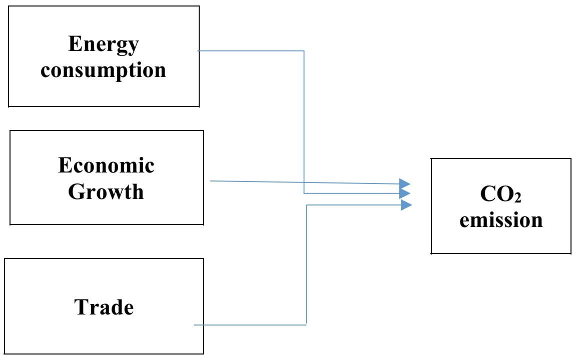

Fig. 1 Conceptual hypothetical framework of the study

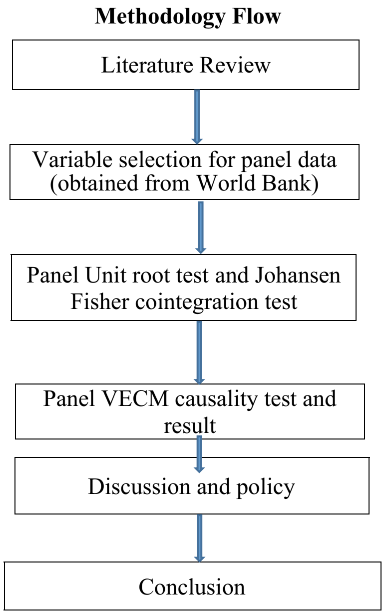

Fig. 2 Methodological flow of the study

the cointegration testing among the variables. In the final stage, Panel Vector Error Correction Model was applied to check the association among the variables. The steps are mentioned below in details. Figure 2 shows methodology flow of the study.

3.2 *Panel Unit Root Test*

The first step of panel data modelling is to check the stationarity test of the variables. The stationarity level is checked by using first difference procedure. We applied Levin Lin Chu, Augmented Dickey Fuller and Philip Perron test for stationarity check. Table 1 shows the result of panel unit root test. It can be seen that all data are non -stationary at levels but when it is converted in first difference, data became stationary.

3.3 *Panel Cointegration Test*

After checking the stationarity level of the variables, second stage required to check the relationship among the variables. Johansen Fisher cointegration test was carried out to test more than one cointegration at one time. The decision criteria was based

Table 1 Panel unit root test result

	LLC		ADF		PP	
Variables	Level	First degree	Level	First degree	Levels	First degree
CEM	4.92026 (1.0000)	−6.22753* (0.0000)	0.2728 (1.0000)	55.7367* (0.0000)	0.15969 (1.0000)	54.8278* (0.0000)
ENR	3.26111 (0.9994)	−4.45811* (0.0000)	1.24000 (0.9962)	45.7287* (0.0000)	1.10064 (0.9975)	50.4375* (0.0000)
GDP	7.39536 (1.0000)	−5.33814* (0.0000)	0.06415 (1.0000)	47.2986* (0.0000)	0.01506 (1.0000)	46.3391* (0.0000)
TRADE	1.87541 (0.9696)	−8.19877* (0.0000)	1.15572 (0.9696)	73.6651* (0.0000)	1.20618 (0.9966)	75.3890* (0.0000)

* Represent significance at 1%. (0.01)
Note LLC = Levin, Li and Chu test, ADF = Augmented Dickey-Fuller test, PP—Phillips-Perron test, CEM—carbon emission, ENR—energy consumption, GDP—gross domestic product, TRADE—Trade

Table 2 Johansen fisher cointegration test result

Hypothesized number of cointegration equation	Trace statistics	Probability value	Max-Eigen statistics	Probability value
None[a]	56.78	0.0000	32.41	0.0001
At most 1[a]	30.29	0.0002	19.34	0.132
At most 2[a]	17.05	0.0296	9.337	0.3147
At most 3	14.60	0.0675	14.60	0.0675

Note [a]shows rejection of null hypotheses at 0.05 test level. This test is based on Chi square distribution

on the value of two test statistics-Trace test and Max-eigen test. The acceptance and rejection depend upon the corresponding probability value at 0.05 test level. The result of panel cointegration test is shown in Table 2.

3.4 Panel Causality Test

After cointegration test, in the third stage the direction of causality among the variables was tested. To do so, we applied Panel Vector Error Correction model.

Further, to analyse the relationship among the variables, we have developed an initial equation.

$$CEM_{it} = \alpha_{it} + \beta_{1it}ENR + \beta_{2it}GDP + \beta_{3it}TRD + \varepsilon_{it} \quad (2)$$

where CEM, ENR, GDP and TRD stands for carbon emission, energy consumption, gross domestic product and Trade respectively. α is intercept term, ε_{it} shows residual with time and countries.

The VECM model can be written with used variables as follows:

$$\Delta \mathrm{CEM} = \alpha 1 + \sum_{t=1}^{k-1} \beta_{1\mathrm{it}} \Delta \mathrm{CEM}_{\mathrm{it-k}} + \sum_{t=1}^{k-1} \beta_{1\mathrm{it}} \Delta \mathrm{ENR}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{1\mathrm{it}} \Delta \mathrm{GDP}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{1\mathrm{it}} \Delta \mathrm{TRd}_{\mathrm{it}-k} + \lambda_{1i} \mathrm{ECT}_{t-1} + \varepsilon 1_{\mathrm{it}} \tag{3}$$

$$\Delta \mathrm{ENR} = \alpha 2 + \sum_{t=1}^{k-1} \beta_{2\mathrm{it}} \Delta \mathrm{CEM}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{2\mathrm{it}} \Delta \mathrm{ENR}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{2\mathrm{it}} \Delta \mathrm{GDP}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{2\mathrm{it}} \Delta \mathrm{TRD}_{\mathrm{it}-k} + \lambda_{2i} \mathrm{ECT}_{t-1} + \varepsilon 2_{\mathrm{it}} \tag{4}$$

$$\Delta \mathrm{GDP} = \alpha 3 + \sum_{t=1}^{k-1} \beta_{3\mathrm{it}} \Delta \mathrm{CEM}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{3\mathrm{it}} \Delta \mathrm{ENR}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{3\mathrm{it}} \Delta \mathrm{GDP}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{3\mathrm{it}} \Delta \mathrm{TRD}_{\mathrm{it}-k} + \lambda_{3i} \mathrm{ECT}_{t-1} + \varepsilon 3_{\mathrm{it}} \tag{5}$$

$$\Delta \mathrm{TRD} = \alpha 5 + \sum_{t=1}^{k-1} \beta_{5\mathrm{it}} \Delta \mathrm{CEM}_{it-k} + \sum_{t=1}^{k-1} \beta_{5\mathrm{it}} \Delta \mathrm{ENR}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{5\mathrm{it}} \Delta \mathrm{GDP}_{\mathrm{it}-k} + \sum_{t=1}^{k-1} \beta_{5\mathrm{it}} \Delta \mathrm{TRD}_{\mathrm{it}-k} + \lambda_{5i} \mathrm{ECT}_{t-1} + \varepsilon 5_{\mathrm{it}} \tag{6}$$

where, ECT_{t-1} is the lagged error correction term, Δ shows first difference, λ is speed of adjustment, k−1 is lag length (reduced by one), β is short run dynamic coefficient of the model adjustment long run equilibrium and ε_{it} is residuals, i and t show countries and time period respectively. The VECM causality results are reported in Table 3.

The short run causality derived from the dependent and independent variables whereas, long run causality from the ECT (−1) statistics. In the short run, unidirectional relationship is noted from energy consumption and trade to carbon emission; and from energy consumption and trade to economic growth. In the long run, there are three causality relationships were observed from energy consumption, economic growth and trade to carbon emission; from carbon emission, economic growth and trade to energy consumption; and from carbon emission, energy consumption and economic growth to trade.

Table 3 Panel causality test result. Based on VECM

Dependent variables	Independent variables Short run				ECT (−) long run
	CEM	ENR	GDP	TRADE	
CEM	–	0.0540* (1.9331)	0.6977 (−0.3886)	0.0204** (2.3291)	0.0375** (−2.0879)
ENR	0.8859 (0.1436)	–	0.9355 (0.0810)	0.4438 (0.7666)	0.0447** (−2.0145)
GDP	0.9028 (0.1222)	0.0630* (1.8646)	–	0.0541* (1.9324)	0.1845 (1.3296)
TRADE	0.6481 (0.4567)	0.5864 (0.5445)	0.1387 (−1.4839)	–	0.0206** (2.3252)

Note p values and t statistics (in brackets). *Shows significant at 10%, **shows significant at 5%, ***shows significant at 1%

4 Discussion and Policy

The discussion is based on the result of VECM provided in Table 3. Beginning from short run causality result, it was found that unidirectional relationship running from energy consumption and trade to carbon emission. It indicates that energy consumption results more carbon emission. Furthermore, higher trade is required after production of goods in large amount and export which ultimately leads to more energy consumption causing significant carbon emission. At this stage, promotion and adoption of clean energy is recommendable for sustainable and low-cost energy consumption. Also, the regulatory requirement to limit of carbon emission could maintain environmental quality and force the industries to adopt the cleaner energy sources.

Further, unidirectional relationship is noticed from energy consumption and trade to economic growth. It indicates that, energy demand increases in the developing economy both by the domestic and industrial uses. Also, trade is directly related to economic growth of the country, rising share in trade help to earn more income which motivates more production of goods and services and more employment. Consequently, income of the people increases and it leads to growth of the nation. Thus, availability of sufficient energy is foremost consideration for an emerging economy to promote its trade that help economic growth. Therefore, environmentally friendly trade policy is required.

Apart from this, long run relationship exists between energy consumption, carbon emission trade and economic growth. It indicates that, any country that use more energy directly causes carbon emission. Economic growth is directly associated with trade due to international export and import. It directs that country is heavily dependent on the export of goods to produce more and sell in the international markets. The reason could be either the domestic consumption is high due to large population or their demand for goods is high in the international market.

Thus, to maintain the economic growth, it is important to consider energy consumption and carbon emission. Reduction of energy consumption means to compromise economic growth. As an alternative, government and policymaker requires to find alternative sources of energy such as clean energy sources- renewable energy, nuclear energy etc. Such sources help to reduce the burden of fossil fuel which can also result in lesser carbon emission, thus maintaining the environmental sustainability.

5 Conclusion

This study examines the impact of energy consumption, carbon emission, economic growth and trade on Argentina, China, Ghana and India both in the short and long term in the period of 1990–2017. The finding shows long term and short-term relationship between the variables. It is noticed that energy consumption influence carbon emission, trade and economic growth. Further, trade facilitates economic growth that leads to energy consumption, consequently, the carbon emission increases. The given challenge can be tackled with the adoption of clean energy sources that helps to gradually replace fossil fuels. In addition, an effective environment policy should be implemented and adopted. Further, this study can be extended to testing more economic variables and time periods with individual country case leading to different results and contribution to the academic literature.

This study has several limitations as well. First, the study examines the effect from 1990 to 2017. However, there might be several structural breaks due to various economic activities and market conditions, in particular the effect of recession would have indicated the different market situation in the short run. Such effect might be observable in 2008 recession. Also, the current Covid-19 pandemic has critically affected the international market. Most of the offices were either closed or asked employees to work from home environment. Thus the shifting of consumption to industry to domestic level might have effected the energy demand in a significant way, which is not covered in the current study. Additionally, a few industries such as pharmaceuticals and delivery/logistic services such as Amazon has witnessed a high growth. Also, IT sector has seen a growth during pandemic, which might have effected the consumption through electronic devices, is also worth paying great attention. In future studies we will identify the limitations and propose to streamline the work in mentioned context.

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Corporate Social Responsibility in the Energy Sector: Towards Sustainability

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Abstract The energy sector faces challenges to ensure long-term supply from reliable sources in order to satisfy demand, which has been growing due to modern lifestyles and technological innovations. Simultaneously, attention needs to be paid to the Corporate Social Responsibility (CSR) and Sustainability of energy companies as they belong to the environmentally sensitive sector. Globalization, industrialization, and urbanization have triggered climate change, emissions, and pollutions. Both CSR and Sustainability address the responsible and sustainable use of resources while considering social, ecological, and economic dimensions of business practice. To increase sustainability and satisfy the demand for energy, countries should develop and utilize renewable resources as well as efficiently use energy sources. Responsible energy companies integrate sustainability into their business strategies. In this chapter, the corporate social responsibility of energy companies is discussed with the emphasis on sustainable energy resources, and sustainability in the energy sector is outlined, followed by the examples of CSR of Bulgarian and Georgian energy companies. The final section deals with conclusions.

Keywords CSR · Sustainability · Renewable energy · Energy companies · Bulgaria · Georgia

1 Introduction

Sustainable Development Goals (SDGs) adopted by United Nations appeals to business for participating in the achievement of 17 goals while engaging in environmental and social responsibility. In particular, the global challenges of poverty, inequality, climate, environmental degradation, prosperity, peace, and justice are addressed in

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the new Global Framework for Sustainable Development agreed by country leaders around the world at the 70th UN General Assembly on 25 September 2015-The 2030 Agenda for Sustainable Development (the Agenda), which is based on the SDGs, and 169 global tasks have been identified, generally applicable and interconnected (EEA 2015). Consequently, the business sector needs to embrace sustainability and corporate responsible behavior. Responsible business practice is expected by investors, employees, customers, and other stakeholders in order to protect the environment, tackle contemporary issues as well as improve the health and safety of society. Moreover, Corporate Social Responsibility (CSR) contributes to decision-making during the crisis and uncertainties to address obscure challenges (Gigauri 2021).

Attention needs to be paid to CSR and Sustainability of energy companies as they belong to the environmentally sensitive sector. Nowadays, the energy sector is experiencing environmental and social problems as the tendency towards renewable energy sources is increasing. Energy companies face challenges to ensure long-term supply from reliable sources in order to satisfy demand, which has been growing due to the modern lifestyle and improved quality of life. However, companies in other sectors engaging in CSR activities take energy-saving measures to protect the environment, on the one hand, and to decrease energy-related costs in the manufacturing process, on the other hand.

There is a certain pressure on all companies to use clean, renewable energy. So, the demand is increasing and energy companies need to discover new sources to meet that demand. Energy is needed for every activity of modern society, as technical advances have improved quality of life, yet some form of energy needs to be converted to be utilized in all segments of economies, from food preparation to manufacturing to transportation and construction (Smil 2017).

Energy efficiency, renewable energy sources, sustainability, and corporate social responsibility are gaining more and more attention from businesses, governments, academic circles, and society. They are vital elements of the modern economy. Corporate responsibility including environmentally friendly business operations is in connection with sustainable development under the current circumstances of globalization, industrialization, and urbanization triggering climate change, emissions, and pollutions. Both CSR and Sustainability address the responsible and sustainable use of resources while considering social, ecological, and economic dimensions of business practice. In order to increase sustainability and satisfy the demand on energy, countries should develop and utilize renewable resources as well as efficiently use energy sources.

In this chapter, we first discuss the corporate social responsibility of energy companies with special emphasis on sustainable energy activities. Then we outline sustainability in the energy sector and investigate renewable energy sources. Afterward, the cases and examples of CSR projects and programs implemented by the energy companies from Bulgaria and Georgia are examined. The conclusions are offered in the final section.

2 Corporate Social Responsibility of Energy Companies to Support Sustainable Activities

The drivers for CSR performance can be reputation, social license to operate, market opportunities, risk prevention, environmental management, business strategy, and corporate culture as well as legislation and regulations, stakeholders engagement, and demands for non-financial information (Gigauri and Djakeli 2021; Latapí et al. 2021). Furthermore, consumers are concerned about the depletion of natural resources and environmental pollutions (Grigorescu et al. 2020). Therefore, CSR enables the achievement of economic profit with the consideration of environmental and social factors to stimulate sustainability (Ene and Panait 2017; Palazzo 2019). Yet energy creates a prosperous society and elimination of energy poverty can improve quality of life (Neacsa et al. 2020). Comprehensive studies proved the link between energy, CO2 emissions, economic growth, and urbanization (Akbar et al. 2020; Nathaniel and Khan 2020; Armeanu et al. 2021).

Increasing energy demands in modern economies indicate that urgent actions are required to change the production and consumption of energy to support sustainability, as energy is a vital source for sustainable economic development (Andrei et al. 2017).

A recent study of the energy companies demonstrated that CSR performance is connected with CSR reports that are prepared in accordance with Global Reporting Initiative (GRI) standards to meet the requirements of regulators, stakeholders (Karaman et al. 2021), law, and society. Energy firms disclose information about CSR activities to address society's environmental concerns in both middle and high-income countries (Karaman et al. 2021). Furthermore, corporate communication as a main part of CSR can create a competitive advantage (Palazzo et al. 2020). Previous studies found as well that CSR commitment in energy companies is improving when the corporate board is gender diverse and CSR-focused (Shahbaz et al. 2020). Responsible energy companies integrate sustainability into their business strategy. This process is continuous and purposeful to achieve outcomes. To be socially responsible, companies take more responsibility voluntarily than simply obeying the law, protecting nature, respecting people, or providing fair working conditions. The business has a proactive and creative role to recognize the challenges and opportunities in society and offer new and innovative approaches to address them (Chankova and Vasilev 2020). Its commitment to the sustainable development of a community, the implementation and maintenance of good business practices can be begun with the ten founding principles of the United Nations Global Compact. Currently, 14 670 companies from 162 countries have joined the initiative and presenting 85 707 public reports regarding their CSR and corporate sustainability activities (UNGC 2021).

To fulfill environmental responsibility, a company changes its traditional business approach to focus on ecological issues through, for example, environmental management system to ensure better performance (Stjepcevic and Siksnelyte 2017). Other sustainability themes such as health and safety, stakeholder dialogue, quality, human rights, and labor issues are also compatible with the environmental management system (Stjepcevic and Siksnelyte 2017). Measurement and management of CSR programs concerning sustainable energy development and communication of the results through CSR reports provide stakeholders (investors, citizens, governmental and non-governmental organizations, partner companies, etc.) comprehension of business operations and the pathway towards the achievement of sustainable goals (Lu et al. 2019). Multiple international initiatives and standards support companies' efforts concerning information disclosure, reporting, and managing sustainable responsibility results. As an example, ISO 26000 provides guidelines to facilitate companies in their CSR efforts. The standard cannot be certified but rather enables sharing social responsibility practices worldwide regardless of the type or size of organizations to measure and manage the influence of their operations considering the following aspects of sustainable development: accountability; transparency; ethical behavior; respect for stakeholder interests; respect for the law; respect for international standards of behavior; respect for human rights (ISO 2018).

Furthermore, Global Reporting Initiative (GRI) aims at facilitating organizations to measure and communicate the sustainability impact of their business processes. Its framework allows companies to prepare Sustainability Reports according to the guidelines and indicators, and facilitates the measurement, disclosure, and improvement of economic, social, and environmental performance (GRI 2021).

Besides, the research results reveal a responsive or proactive approach to execute corporate and sustainable responsibility (Latapí Agudelo et al. 2020). The energy sector puts certain pressure on ecosystems by producing, transmitting, distributing, and using the energy, and hence, the life cycle of the product should be altered from input—natural resources, fossil fuels, water, to waste outcome - emissions and pollutions resulting in climate change, depletion resources, declining of biodiversity, and harmful impact on people's lives around the world (Stjepcevic and Siksnelyte 2017). The targets of the UN sustainable development goals are related to sustainable energy development such as improving energy efficiency, using renewable energy sources, and decreasing GHG emissions (Lu et al. 2019). Scholars suggest three pillars of sustainability to energy companies: social, environmental, and economic responsibility (Fig. 1). Social responsibility includes employees' well-being and development, communication with stakeholders, partnership with different organizations, fair price for energy products. Environmental responsibility addresses the management of environmental impact, decreasing pollution, developing renewable sources, and constant monitoring waste and emissions. Economic responsibility involves effective operations, introducing novel technologies, managing financial risks, and ensuring reliable energy supply (Stjepcevic and Siksnelyte 2017).

The energy sector encounters various risks in terms of ecology, health, and safety, reputation, which can impede their success on the market, but also citizens, as well as governmental and non-governmental organizations, expect energy companies to have solid sustainability achievement, and consequently, CSR is considered to be a duty and requirement (Stjepcevic and Siksnelyte 2017). To cope with the growing pressure, energy companies must exceed legal requirements by adopting CSR, while not only responding to external forces but also avoiding risks and proactively managing

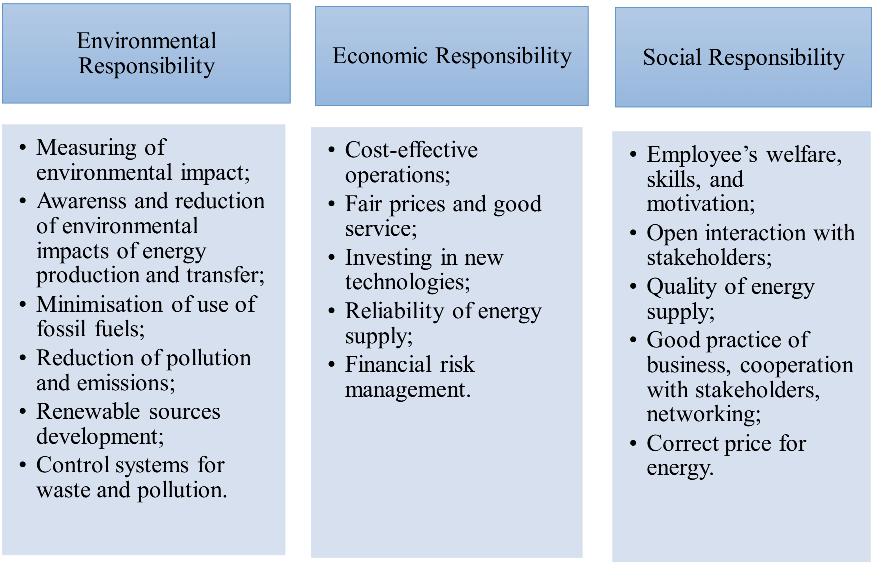


Fig. 1 Responsibility framework of energy companies. *Source* Based on Stjepcevic and Siksnelyte (2017)

their environmental impact, especially, in the current circumstances of climate change (Latapí Agudelo et al. 2020). Moreover, CSR initiatives help energy companies to develop sustainable energy and minimize risks that are created by the industry (Lu et al. 2019). Accordingly, incentives for implementing CSR initiatives in energy companies can be grouped into economic, political, and social factors (Fig. 2). Economic drivers include company reputation and image, risk management, competitiveness, increased attention of society to environmental problems. Social incentives concentrate on pressures from various stakeholders, and political stimulus encompasses a legal framework (Stjepcevic and Siksnelyte 2017). Energy companies have a greater economic motivation to engage in corporate responsibility activities and contribute to sustainable development than legislation offers or is determined by societal pressure.

In addition, the studies also indicate "five internal drivers, three connecting drivers, and four external drivers" as incentives for energy companies to implement CSR (Latapí Agudelo et al. 2020) (Fig. 3). Internal incentives concentrate on business strategy, organizational culture, environmental commitments and risk prevention, while connecting factors comprise branding and image, reporting and information disclosure, and social license (Latapí Agudelo et al. 2020). External forces for CSR accomplishment in the energy companies highlight competitive advantage, legislation and regulations, social engagement, and stakeholder satisfaction (Latapí Agudelo et al. 2020).

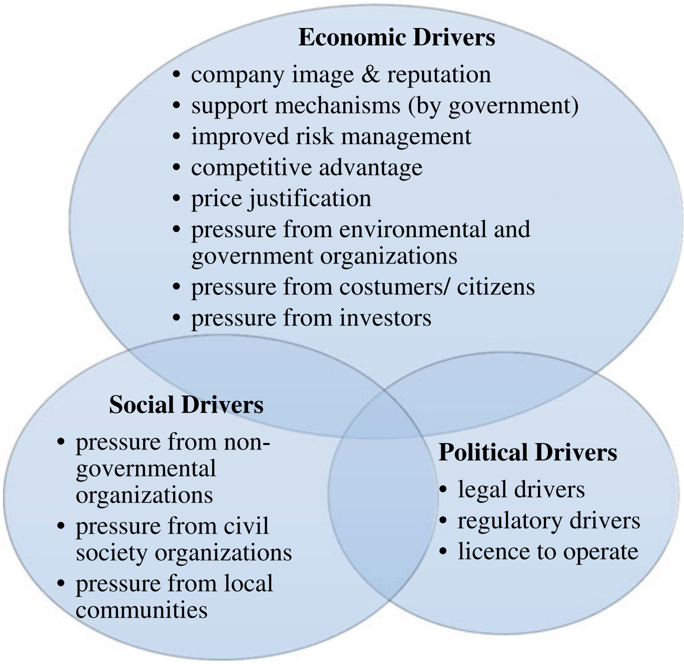


Fig. 2 Motivation of energy companies for CSR. *Source* Based on Stjepcevic and Siksnelyte (2017)

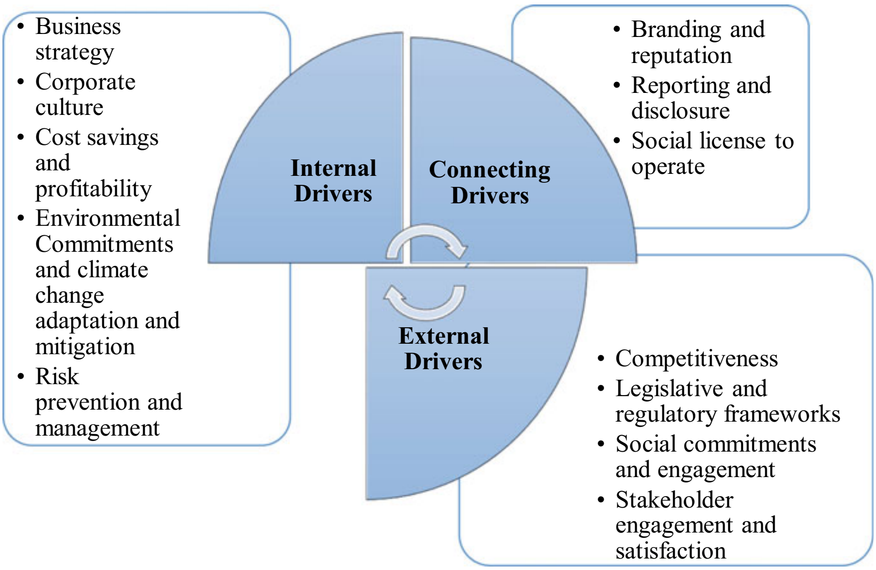


Fig. 3 CSR drivers in the energy sector. *Source* Based on Latapí Agudelo et al. (2020)

3 Corporate Social Responsibility of Georgian Energy Companies

In Georgia, the sector is regulated by the Georgian National Energy and Water Supply Regulatory Commission (GNERC), which is responsible to protect customers. The retail market for electricity and natural gas in Georgia has both regulated and unregulated prices (Szilágy and Pirashvili 2021). There are household and non-household consumers in electricity, while there are no distinct groups in natural gas (Szilágy and Pirashvili 2021).

The energy service providers are obliged to respond to the consumer complaints, and if the consumers are not satisfied, they can turn to the regulator or energy ombudsmen. The Regulatory Commission in Georgia received 1 928 complaints in 2019 compared to 1 759 complaints received in 2015 (Szilágy and Pirashvili 2021). Besides, the service provider companies are obliged to notify consumers about the disconnection, yet, the procedures cannot be accomplished if it would harm the health of a consumer (Szilágy and Pirashvili 2021). As the Georgian government provides additional protection to vulnerable citizens, 380 000 consumers are subsidized in the energy sector (Szilágy and Pirashvili 2021).

In Georgia, there are state and private energy companies. The major direction under CSR is focused on environmental protection. For instance, a state company—*Georgian Oil and Gas Corporation* as a diversified company is active in various segments of energy. Its business model is based on three directions: Natural gas supply, Oil transportation, and Power generation and supply (GOGC 2021). The company discloses statistics regarding oil transit, natural gas transit, stock tank oil production and sharing, commercial gas production and sharing, and power generated by thermal powers plants (GOGC 2021). Through its webpage, the company offers information for investors, including financial reports, and consolidated statements, credit ratings, and studies on the company and its results (GOGC 2021). The company has a corporate strategy in health and safety and environmental policy. Under CSR projects, they initiate social and charity projects, but most importantly, they publish Environmental Impact Assessments Reports and Sustainability Strategy on the website (GOGC 2021). The company's environmental policy aims at protecting the environment, reducing the negative footprints, and achieving modern standards in the area. It also ensures its contractors comply with the environmental policy and standards (GOGC 2021). In addition, before implementing projects, the studies of environmental components, and environmental consequences are conducted and mitigation measures are planned (GOGC 2021). However, it is noteworthy that the company does not present non-financial information on its website, neither CSR nor sustainability reports are publicly available.

Another state company *Georgian State Electrosystem* provides electricity from hydro, thermal, and wind power plants to distribution companies as well as to direct business customers (GSE 2021). They conduct Environmental Assessment in accordance with the Georgian legislation and international standards and guidelines (e.g. IFC, EBRD, KFW, WB, ADB). Each project is evaluated in compliance with the requirements of the funding source. Thus, the projects must be designed and operated in accordance with the health and safety guidelines, environmental impact assessment, international performance standards and practice, sustainable development including management of social, environmental, and climate aspects (GSE 2021). However, the company does not disclose information concerning the results of environmental assessments. There are no CSR or sustainability reports accessible publicly on the website of the company. Though they present Environmental and Social Policy, which declares the company's commitment to comply with sustainable development, environmental protection and corporate social responsibility principles (GSE 2021). The company aims at introducing Environmental and Social Management System (ESMS). It strives to satisfy the requirements in order to obtain ISO certificates in environmental management (ISO 14001), for occupational health and safety management (ISO 45001), and for corporate social responsibility (ISO 26001) (GSE 2021). It is worth noting that the company recognizes the importance of health and safety issues of its employees as they might work in a hazardous environment, and provides qualification and professional development training as well as takes improvement measures to ensure a secure working environment (GSE 2021).

CSR of a private electric power company—*Telasi* concentrates on employees, health and safety of employees, as well as social and charity activities (Telasi 2021). The company elaborated Environmental Policy in 2015 in accordance with the Georgian legislation and international standard ISO 14001, which enables to monitor environmental impact through the management system. The company declares environmental protection as a key part of its operations and ensures improvement of environmental performance through its Environmental Management System. The environmental policy document and ISO 14001 certificate are available on the webpage of the company (Telasi 2021). The company recognizes that Environmental Management System makes it possible to reduce the negative impact on the environment, decrease the number of emergencies and accidents, increase the competences of employees to lower the accident rate of technical facilities, and build ecologically responsible behavior (Telasi 2021). However, it is worth emphasizing that the document is already old and the company should present the environmental monitoring results on its webpage, though the reports are available for shareholders and annual reports are accessible through its webpage as accounting information for shareholders (Telasi 2021). The report includes both financial and non-financial information, while the financial report is more comprehensive. The non-financial report, in particular, the CSR report contains data about human resources and HR management policy; the chapter about environmental protection states that the company reassured the requirements of ISO 14001:2015, but the document does not disclose information concerning the environmental control and ecological data about the company's impact on the environment.

According to the website of energy distribution business company—*Energo-Pro Georgia*, they are aware of ecological and social responsibility, their projects are in compliance with environmental standards, and try to decrease the negative footprints in order to protect the ecosystem (Energo-Pro Georgia 2021). As the company uses oil products in operations and there might be some minor leakage, they clean the soil with "ecologically safe biospecimen made on the basis of micro-bodies" produced by the Scientific-Practical Center for Eco Technologies to ensure long-term environmental sustainability (Meliora 2018). The company presents several documents on its webpage concerning corporate responsibility behavior. For example, Anti-bribery and Anti-money Laundering Policy recognizes the risks and aims at ensuring "all employees and associated persons act lawfully and with integrity when performing their work", as well as avoiding bribery and money laundering (Energo-Pro Georgia 2021). The document specifies the required behaviors and reporting obligations (Energo-Pro Georgia 2021). Additionally, the Sustainability Policy document is committed to the sustainable development and protection of the community living in the areas of company operations, and recognizes that the policies and practices of the company shape the lives of both current and future generations. Therefore, the sustainability issues are integrated into the company's day-to-day operations (Energo-Pro Georgia 2021). For this reason, the company adopts the Universal Declaration of Human Rights, international environmental conventions, the framework agreements regarding climate change, and the Paris Agreement, the International Labor Organization (ILO) Conventions (Energo-Pro Georgia 2021). The company joined the United Nations Global Compact in 2021 to adhere to the universal principles in the areas of human rights, labor, the environment, and anti-corruption. Accordingly, the company plans to present its first ESG official report in 2022. In its Sustainability Policy document, the company also defines sustainable development commitments in terms of management and governance, environment and biodiversity, population and social responsibility, human resources (Energo-Pro Georgia 2021). Moreover, the Global Code of Conduct of Energo-Pro Georgia is available on the webpage of the company, which covers the company values, the purpose and application of the Code of Conduct, responsibilities of employees, suppliers, and contractors, violations of the Code of Conduct and disciplinary measures (Energo-Pro Georgia 2021). The following 4 priorities are highlighted in the Code of Conduct:

- work environment, employees, health and safety;
- personal data protection, anti-corruption and money laundering, conflict of interest, fair competition and antitrust policy, access to internal information and training;
- partners, government, suppliers and contractors, political parties, religious organizations, and trade unions;
- Sustainability and Environmental, Social, and Corporate Governance (ESG), society and stakeholders, human rights, and effective management structures, transparency. and accountability (Energo-Pro Georgia 2021).

4 Corporate Social Responsibility of Energy Companies: The Experience of Bulgaria

For more than a decade, a large part of the media seems to impose in the society the opinion that the measures for energy transition and climate policies in Bulgaria seem to be mainly imposed by the EU and are against the national interests. However, we must strongly emphasize that the search for a better quality of life for Bulgarian citizens and care for their health, which includes land rehabilitation, clean air, and environmental protection, renewable energy, and innovative solutions in nature and resource protection is in the national interest and not imposed "under pressure from Brussels". The key point in linking the vision of the relationship between energy policy and social responsibility is undoubtedly the strategic approach in these processes, including on the basis of targeted EU policies in various directions (European Commission 2021). In Bulgaria, it has become a tradition to upgrade these measures permanently. In this regard, the "Strategy for Corporate Social Responsibility 2019–2023" was developed and adopted at the national level, as a symbol of a new approach in perceiving the importance of CSR in government and business. Through the Strategy, the Government of Bulgaria presents its vision, priority goals, and commitment to foster the company capacities to incorporate their CSR practices in their operations in order to enhance competitive power, business sustainability, and facilitate the implementation of the goals of sustainable development, and this is also relevant for organizations that are in the energy sector.

It should be noted that as a result of the implementation of the priorities and the activities outlined in the framework of the first CSR strategy 2009–2013, as well as a result of independent initiatives carried out by stakeholders, significant progress is noted:

- The number of enterprises in Bulgaria that have accepted the ten principles for CSR of the UN Global Compact in just 5 years, by 2018, has grown by more than 150 percent;
- Increased number of companies that publish reports and disclose non-financial information as required by Directive 2014/95/EU of the European Parliament for reporting non-financial information;
- The number of companies that have stated compliance with the principles of the National Corporate Governance Code, applicable to public companies has reached 53 associations.

The analysis of the environment shows that most of the good examples in Bulgaria are mainly of private sector companies, with a large number of employees who are aware of the impact they have on society and have allocated resources, mainly financial, for the implementation of activities in the field of CSR (Vasilev 2021). At the same time, more and more structures from the public sector are implementing CSR policies, and this is set to become a lasting trend.

In this context, it is necessary to emphasize that Bulgaria is among the countries that have reported consistent and measurable progress in their energy transition over the past six years, along with Argentina, China, the Czech Republic, Ireland, Italy, and others (WEF 2020). An annual ranking of how well countries are able to balance secure and affordable energy supply and environmental factors, Bulgaria ranks 61st out of 115 countries, with Sweden, Switzerland, Finland, Denmark, and Norway in the first places and Georgia in 41st place (WEF 2020).

The actions of companies have significantly influenced the lives of citizens nationally and internationally. The impact includes the products and services they provide, and the jobs or opportunities they create, taking into consideration working conditions, human and employee rights, health and safety, the environment and ecosystem, innovation, and education (Vasilev 2020), which is particularly important for the energy sector.

For companies, CSR offers advantages to manage risks, save costs, get access to capital, improve customer relations and human resource management, create innovations, make them more competitive, and finally increase profit. From the economy's point of view, CSR facilitates sustainable economic growth. In addition, CSR offers society values regarding solidarity, responsibility, and sustainability (European Commission 2021). For this reason, EU citizens, and in Bulgaria in particular, rightly expect companies to be aware of the positive and negative consequences of their actions towards society and the environment. Therefore, by following CSR policies, companies should implement effective solutions to prevent, manage and mitigate the negative consequences they can trigger, including within their global supply chain, and of course, this is relevant and to the new trend of expanding the application of the so-called "green management" of human resources (Saifulina et al. 2020).

An illustration of the above, the guiding principle in the development of the Strategy is the voluntary implementation of actions in the arena of corporate responsibility. By its nature, CSR is a commitment on the part of the company's management to ensure that management decisions and daily actions take into account the specific interests of customers, suppliers, consumers, employees, and the public located in the areas in which the company operates, including in the field of the environment and of all other entities to which its activity is directly or indirectly related. A key prerequisite for the implementation of CSR activities and policies is the principle to "Do good", i.e., anyone who intends to implement CSR practices should, before proceeding with their implementation, have correctly fulfilled their legally imposed obligations.

Through the Corporate Social Responsibility Strategy, the Government of Bulgaria aims to support the creation of the necessary prerequisites for the participation of all stakeholders—governmental and non-governmental institutions and organizations, business, social partner organizations, civil society organizations, academia, media, etc. in the development and the implementation of a policy of social responsibility and investment in socially responsible practices (Government of Bulgaria 2014). The vision for the role of the government in this process is to create supportive public policies and framework norms that will allow the use of various instruments - legal, financial, information, economic, etc., also in combination, including in the critical energy sector. For the period of validity of the Strategy, the realization of three implementation plans is envisaged, as it is envisioned to achieve coordination with measures from other strategic documents in the field of human resources development, employment, demographic policy, energy, and environmental protection, education, etc. The CSR strategy provides a forward vision for future changes in the regulations and practices of state bodies. It is a document that integrates sectoral policies and measures envisaged for their implementation.

Compared to the period of implementation of the previous Strategy 2009–2013, it should be noted that from a standard of business ethics, CSR is becoming a successfully developing management model, which is the basis of global policy for sustainable development. This requires extending the scope of the Strategy to civil society organizations and the public sector.

The main stakeholders in the implementation of the Strategy are the company management, the management units of the public institutions, and the employees. In a wider range as directly interested, we can add consumers of goods, services, and administrative services provided by public administration, corporate clients, and subcontractors in the chain with the whole range of their system, social partners, civic and academic structures, and last but not least—the environment and its surrounding ecosystems.

The vision of the Strategy is Sustainable development of competitive, attractive for the labor force, socially inclusive business structures, administrative bodies, and civil society organizations, ensuring decent work and balance of interests between stakeholders (Government of Bulgaria 2014). Corporate social responsibility includes the public commitment of organizations to the community, environmental protection, and the establishment of quality relationships with all stakeholders.

Due to the dynamic development of the topic of CSR, it is possible to update the Strategy if it is proven necessary, which implies its consideration as a dynamically developing philosophy and public agreement on the main aspects and essence of the topic. The responsible body that will coordinate the implementation of the Corporate Social Responsibility Strategy is the Ministry of Labor and Social Policy.

In a wider range, stakeholders are increasingly required to make ethical choices and make quick decisions in a complex environment. Through socially responsible behavior, business organizations and public structures facilitate the informed choice of the individual, making this privilege an individual responsibility for the decisions made. This creates reciprocal relations of socially responsible behavior and establishes a culture of socially responsible supply, consumption, and attitude, which undoubtedly affects motivation in many ways (Icheva and Vasilev 2021).

In Bulgaria, large companies begin to apply a sophisticated approach to CSR and integrate internal management systems as well as CSR standards in their business strategy (CSR Advice Box 2020). Moreover, 83% of Bulgarian companies publish CSR reports and 87% define CSR among their priority goals (CSR Advice Box 2020). Companies apply international CSR standards such as United Nations Global Compact, Global Reporting Initiative Standards (GRI), ISO 26000 Guidance, OECD Guidelines for multinational enterprises (CSR Advice Box 2020).

The Bulgarian Global Compact Network has implemented a number of initiatives, the part of which are companies in the energy sector. The most successful and popular among them are:

- "Proud of my parents work" and "Children's Bazaar of Professions", which aim to present to the children different professions in an intriguing way for them;
- "Games for good"—aims to show that responsible business, good health of employees, sports, and support for social causes can go hand in hand;
- "The responsible choice"—shows consumers their exceptional strength, that they define the market and can influence production by responsibly choosing what and from whom to buy;
- Green initiatives related to World Environment Day, such as the Break free from Plastics campaign (UN Global Compact 2021).

Interestingly, when a company joins such an initiative and collective project, we are already talking not just about corporate social responsibility, but about collective social responsibility—CSR 2.0. What is characteristic here is that they combine capacity and resources from different sources, which leads to a new level of efficiency and effectiveness. More significant results and higher quality are achieved, the invested resources are better absorbed (Tennant 2015).

Accordingly, the benefits of collective social responsibility for businesses engaging in the energy sector could be as follows:

- better recognition by customers, partners, clients, etc.,
- improving employee branding, which, in turn, increases employee loyalty and motivation; creates a sense of significance, empathy, and belonging,
- the company and its employees become part of a movement that does good and makes the world a better place,
- companies can quickly and easily join projects that are already proven successful, and this saves effort and resources,
- businesses are building new partnerships,
- there is a synergy that gives more meaningful results, satisfaction, and motivation.

Moreover, the interest in CSR in Bulgaria led to the establishment in October 2018 of the Bulgarian Association of CSR Specialists, with the purpose to create and establish professional standards and a favorable public environment for a positive attitude towards the specialists of corporate sustainability and social responsibility (BACOS 2021). The organization includes more than 40 leading specialists in the field of corporate responsibility and sustainability, who have been working for years for the development and implementation of this concept in Bulgarian companies, including leading companies in the energy sector (BACOS 2021).

The practical examples of CSR activities of Bulgarian energy companies are different and focusing on social and environmental issues.

The main electricity generating plant in Bulgaria (Kozloduy NPP), the only nuclear power plant in the country, has Environmental Monitoring system that measures its ecological footprints and makes information available on its webpage (Kozloduy NPP 2021). The company is moving towards clean energy and sustainability contributing to decarbonization and reducing negative impact on the environment; it does not generate any greenhouse gases (Kozloduy NPP 2021). The company attracts young professionals who can engage in the implementation of their values.

The social activities of *Assarel Medet AD*, one of the largest mining companies, located in the town of Panagyurishte, are exceptionally effective. In addition to supporting the construction of an ultra-modern hospital in the city, which is also used by residents, the company's efforts are focused mainly on promoting dual education. 91 students are trained at the Vocational High School in Panagyurishte with the support of the company, studying in a real work environment and on an employment contract. The company organizes various training and prepares the mentors of the students in advance.

All employees of the company can participate in the programs of the electricity distribution company *EVN for Bulgaria* and voluntarily support a local cause from the area in which they work. They apply to a committee and if their idea is approved, they receive a budget, the necessary equipment, and working time to implement it. At the moment, more than 750 employees (Dobryatsi) have joined the campaign. In 2017 alone, 44 volunteer actions were realized. *EVN for Bulgaria* also implements other initiatives. The "energy playground" is a combination of 4 swings and is designed for children from 3 to 12 years. The unique thing about swings is that they not only stimulate children's physical activity and group play, but when used, they capture the kinetic energy of movement. It is visualized by LEDs as each swing glows with its own light. When the 4 swings are driven by the children at the same time, figures of houses light up in the middle of the playground. Thus, in the form of a game, the principle is illustrated that in order to produce energy, it is necessary to perform a certain action, and in the case of coordinated actions, a greater result is achieved.

The main part of the vision of *EVN for Bulgaria* is the program for training students in the rational use of energy and nature conservation. The entertaining lessons "The Hour of Ivy and Encho" are conducted by the teachers in 4 school hours during the year in the Class Hour over 320 classes from 2nd, 3rd, and 4th grade in a total of 44 schools in Southeastern Bulgaria. The "energy lessons" are conducted also with the support of the Ministry of Education and Science, the regional inspectorates of education and the schools participating in the training program. The company started the training on energy efficiency in 2009, and by the end of 2013/14 a total of over 11,700 children will have participated in the lessons on rational use of electricity (EVN 2021). "Solar bench" is another idea of the company, realized in Burgas, which gives the residents and guests of the city the opportunity to charge their phones and tablets directly from the sun. The panels on the top of the bench generate energy to charge up to four mobile devices at the same time using a USB cable (EVN 2021).

"Communicating together" is the Social Campaign of *Stabil Group*—a holding company located in Plovdiv. The project is in cooperation with the Elijah Foundation. The ultimate goal of the campaign is to create and donate over 100 communication folders to families raising autistic children, as well as to provide as many centers as possible that deal with children with special needs.

To conclude, the Bulgarian government needs to clarify to both citizens and businesses the medium and long-term strategies in the energy sector. The clear understanding that reforms are definitely needed in the energy sector, simultaneously, the question of their price arises primarily in economic and social terms. Besides, the main contradiction that undermines the credibility of environmental measures is the understanding that they are the reason why many jobs are disappearing. This must be denied consistently because it is simply not true and the role of CSR would be significant in this direction.

Finally, a fair energy transition in Bulgaria is possible, but its success depends on good planning, and participation of national, regional, and local institutions, businesses, trade unions and the public. According to the For the Earth initiative, the basis for the success of the transition is the extent to which the social element is well planned and implemented while conserving natural resources, as well as the implementation of actions for decentralization of energy production (For Earth 2021).

5 Achieving Sustainability through Sustainable Resources. Renewable Energy Sources in Georgia and Bulgaria

Today's society is facing challenges to develop and utilize natural resources sustainably without depleting and polluting the ecosystem. Issues such as the growth of population, depletion of energy resources, environmental degradation, and climate change can be solved by changing mindset towards sustainable energy (Kutscher et al. 2018) and responsible business practice to contribute to sustainable economic development.

Interestingly, the population increased from 1 to 2 billion in 118 years, while the number doubled from 3 to 6 billion in only 40 years (Kutscher et al. 2018). Smil (2017) considers energy and economy as synonyms since every economic activity is based on the transformation of one kind of energy to another. Energy demand is rising in the world, whereas the agenda of sustainable growth highlights the climate change and global warming issues, which requires generating and consuming energy in a way to minimize environmental damage (Sharma and Kar 2015).

Presently, about 85% of commercial energy is produced from fossil sources worldwide (Kutscher et al. 2018). Industrialization and urbanization have triggered the shift from solar energy usage to expanded utilization of unsustainable energy (e.g. fossil fuel) to achieve high standards of living, but also this movement caused deterioration of the environment and inequality in energy distribution (Smil 2017). Modern lifestyle imposes grown electricity demand for air conditioning, washing machines (Kutscher et al. 2018), heating, computers, and other devices. The solution to this growing problem lies in the balance between technological progress, improved quality of life, and maintaining enough resources for future generations to satisfy their needs (Kutscher et al. 2018). Therefore, sustainable development is indispensable.

Transformations in the economic development of the Eastern European countries led to changes in the energy sector which were required by the European Commission to generate energy increasingly from renewable sources (Bratiănu 2016).Renewable energy includes solar, wind, geothermal, hydropower, biomass, biogas, ocean (wave) energy, in short, non-fossil sources. Renewable energy technologies such as wind turbines, solar thermal plants, or photovoltaic cells generate electricity (Kutscher et al. 2018).

Although fossil fuels are blamed for climate change as their usage for producing energy causes carbon dioxide emissions (MacKay 2009; Moradibistouni et al. 2019), alterations in demand and supply are required to switch from fossil fuel energy to renewable energy sources (MacKay 2009). Renewable energy has the potential to supply the energy needs without harming the ecosystem, but its share in the energy sector needs to be increased in order to produce and distribute sustainable energy (Sharma and Kar 2015).

The solar photovoltaic system is a renewable energy source that has gained more importance recently to reduce greenhouse gas emissions worldwide (Phadnis et al. 2019). The market for photovoltaic solar cells has been increasing rapidly, but energy storage systems have still to be ameliorated (Kutscher et al. 2018). Wind power as a renewable source to produce electricity is accelerating (Kutscher et al. 2018). Wind energy is seen as a promising option to replace unsustainable energy supply from fossil fuel and hence, avoid environmental problems, greenhouse emissions, and air pollutions (Warudkar 2015). Nevertheless, the noise of turbines and their effect on the landscape need to be taken into consideration while building the plants. Through thermal processes, biomass can be converted into solid (charcoal, torrefied), gas (biogas), and liquid (ethanol, biodiesel) products (Wright and Brown 2015). Thus, renewable, non-polluting resources of energy, as well as environmentally friendly technologies, should be further developed to achieve sustainable growth in the energy sector.

Georgia is a country of 3.7 million inhabitants in an area of about 69,700 km^2 located in the South Caucasus (Eurasia). The population of Bulgaria amounts to 6.8 million in an area of 110,993 km^2, located in Southeast Europe. Sustainable development, as well as the engagement of business in corporate social responsibility, are influenced by regional characteristics.

Georgia has hydropower, the solar, wind, and bioenergy potential. The country's special potential to expand solar power generation and development is still to be explored. Conversely, biomass as the energy source is almost not used in Georgia. Whereas hydropower is the main source of energy in Georgia. However, the majority of dams are built during the Soviet era and requires technological upgrades to meet new standards. Notably, the water-storage plants are also recreation sides and sight-seeing attractions.

There are foreign companies operating in the renewable energy field in Georgia. As an example, Clean Energy Invest develops the hydropower potential in the country (Clean Energy Invest 2021). Besides, there are also Georgian companies starting to developing and utilizing renewable energy sources, such as bio–or solar energy. However, the scale is still small.

In Georgia, the electricity is mainly (80%) produced by hydro(electric) power plants, while a wind energy plant has been operating since 2016, and there is no nuclear power in the country (OECD 2018). According to the Georgian National Energy and Water Supply Regulatory Commission, the country's potential for wind resources amounts to 1450 MW (GNERC 2021).

Fig. 4 Total renewable energy, 2012–2020. *Source* Authors based on data by IRENA (2021)

Renewable energy generation capacity is increasing over the recent years in the world. In 2017, global renewable generation capacity reached 2 179 GW, whereas the share of new renewable capacity in Asia was 64% and wind and solar share—85% (IRENA 2018). 146 million people used renewable power - off-grid electricity (IRENA 2018).

The increase is also intense at the regional level—Europe and Eurasia (Fig. 4). Eurasia includes the following countries: Armenia, Azerbaijan, Georgia, Russian Federation, Turkey.

Global renewable energy generation increased from 1 442 763 MW in 2012 to 2 799 094 MW in 2020, while in Eurasia the growth was smaller (from 76 692 MW to 110 241 MW), and in Georgia, the capacity increased by 1 129 MW, in comparison with Europe from 395 154 MW to 609 499 MW between 2012–2020, and the capacity in Bulgaria raised only by 326 MW (IRENA 2021).

The generation of Hydropower as a renewable source of energy is developing as well (Fig. 5). The capacity has been grown by 1 108 MW in Georgia, and by 197 MW in Bulgaria (IRENA 2021).

At the same period, Solar energy capacity increased worldwide, especially in Eurasia from 13 MW to 8 231 MW, and in Europe from 73 723 MW to 163 466 MW in 2020 (IRENA 2021). However, the raise was not impressive in Georgia (from 1 to 40 MW) and in Bulgaria (from 1 013 to 1 073 MW) (Fig. 6).

With regard to wind energy, its capacity increased globally between the years 2012 and 2020, reaching 207,747 MW in Europe and 9867 MW in Eurasia (Fig. 7). However, in Georgia, its capacity merely is 21 MW, and in Bulgaria—703 MW (IRENA 2021).

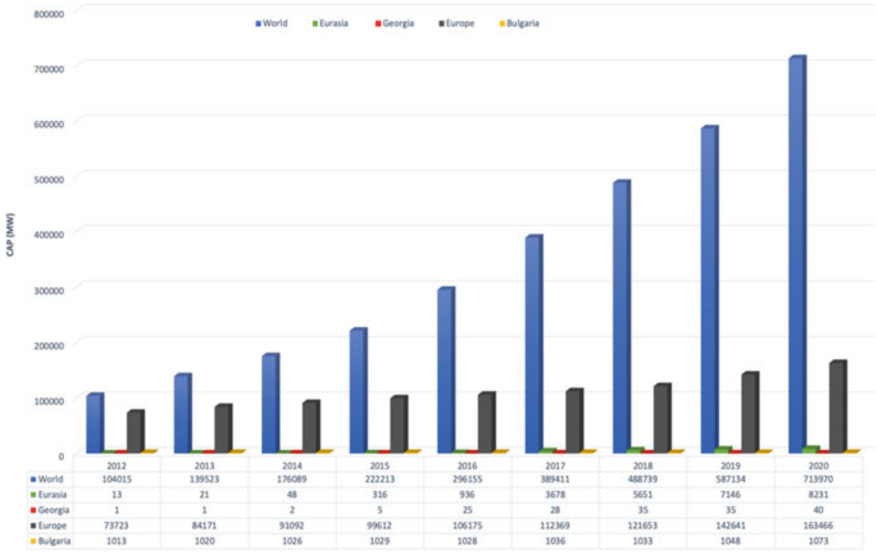


Fig. 5 Hydropower capacity, 2012–2020. *Source* Authors based on data by IRENA (2021)

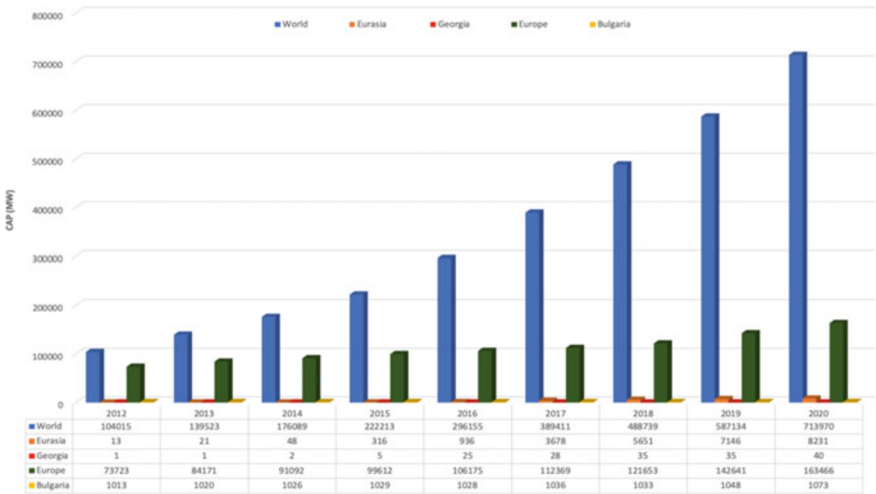
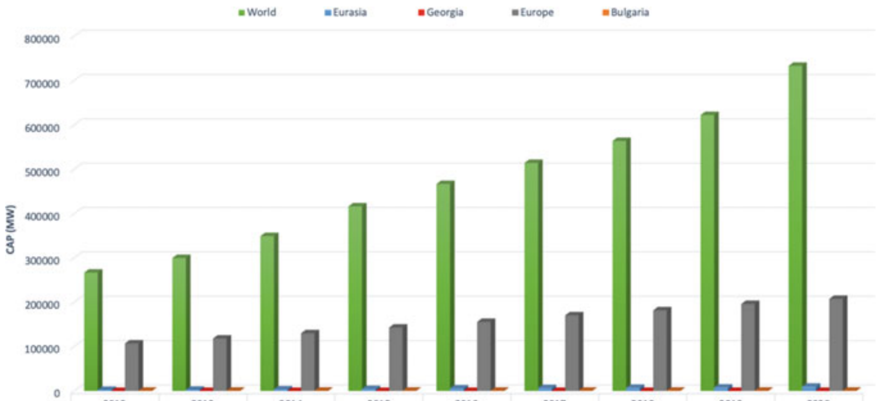


Fig. 6 Solar energy capacity, 2011–2020. *Source* Authors based on data by IRENA (2021)

Overall, the energy sector in Georgia needs further development, especially, in terms of renewable sources, in order to utilize its full potential, avoid energy losses, and ensure energy security. However, companies need to take into consideration the opinion and attitude of local citizens regarding renewable energy plants and their possible locations, especially, for wind turbine plants. Cooperation with various



	2012	2013	2014	2015	2016	2017	2018	2019	2020
World	266908	299919	349300	416248	466864	514374	563830	622249	733276
Eurasia	2274	2775	3645	4525	5801	6566	7147	7783	9867
Georgia	0	0	0	0	21	21	21	21	21
Europe	107191	118263	130204	143033	155756	170624	181963	196311	207747
Bulgaria	677	683	699	699	699	698	699	703	703

Fig. 7 Wind energy capacity, 2012–2020. *Source* Authors based on data by IRENA (2021)

stakeholders is essential as a part of the corporate social responsibility of a company even if the company is operating in the renewable energy sector.

Awareness should be increased among citizens towards renewable sources of energy, education programs need to be established, attention from the government is to be given to the issue. For instance, subsidies need to be made available not only for the development of sustainable sources of energy but also for energy efficiency and energy audit programs for any size and type of firm. Tax incentives can also be provided in a form of deductions, credits, for investing, building, or developing renewable energy sources as well as for efficient consumption of energy. In general, Georgian and Bulgarian energy sectors need to align with industry norms and applying energy management standards.

6 Conclusions

Today's society is facing environmental issues that requires progress towards sustainability. To prevent environmental degradation, water, and air pollution, and protect the ecosystem energy should be consumed efficiently. Prosperity depends upon efficient and affordable energy, but the energy demand has been augmented to previously unthinkable levels due to the modern world. Under such circumstances, CSR can promote the responsible behavior of energy companies.

The increased pressure on the energy sector to consider the ecology and reduce a negative impact on the environment imposes companies to move towards sustainability, utilize renewable energy sources, and conduct responsible business behavior.

Fuel energy resources are exhausting and need to be replaced with renewable energy sources. However, as the stone age did not end due to the lack of stones but because of the invention of new, more effective and efficient tools made by bronze, renewable energy technologies will replace non-renewable energy sources without of shortage of fossil fuel. The energy transition is already occurring along with the growing concerns for environmental issues.

Renewable energy generated from solar, wind, biomass, or ocean has become a promising measure towards the future with clean, green, and sustainable energy that is developed and consumed with responsibility. In essence, before developing renewable energy plants, companies ought to consult with locals within the framework of their CSR strategy, as stakeholder attitude plays a pivotal role in decisions regarding plant locations and operations.

Finally, awareness towards renewable sources of energy should be raised and governmental involvement can be crucial in the energy transition to develop a sustainable economy.

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Energy Transition in European Union—Challenges and Opportunities

Catalin Popescu, Mirela Panait, Maria Palazzo, and Alfonso Siano

Abstract The energy topic is essential for the present period, but especially for the future. The amount of energy required, year by year, globally is increasing and become expensive to be produced. The current challenges are related to the health crisis generated by the COVID-19 pandemic, increasing energy prices, rising greenhouse gas emissions but with a major effect on global warming, promoting the new industry Industry 5.0 and the Digital Age through worldwide economy, a possible global power outage, food crisis, the massive increase in the world's population, the extinction of some species of animals and birds, the massive pollution of water, air and soil, the huge volume of waste of all kinds but especially household, depletion of conventional resources. The solution to these problems is answered through a responsible, mature and attentive attitude towards the environment, in relation to the respect that humanity must have for the legacy it must leave to future generations. This requires a rapid and efficient intervention of international, national, regional and local authorities but also a change in the attitude of each person towards nature. Urgent and effective measures are necessary and mandatory, sustainable development strategies can save the planet from extinction. Because energy is at the heart of everything that happens on the planet, permanent concerns for how to produce, use and save energy is a top priority for everyone. Knowing and informing people about how energy issues are handled by the authorities will help to the understand and solving many difficult situations that humanity may face in the near or distant future. This paper aims to identify the main steps taken at EU level in the process of

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energy transition, the authors emphasizing the special involvement of public authorities trying to shape the behavior of companies and consumers, given the complexity of the phenomenon and its importance in creating a low carbon economy.

Keywords Energy transition · Energy security · Climate change · Global warming · Greenhouse gas emissions · Renewable energy

1 Introduction

Undoubtedly, the problem of energy is one of the most important topics of the present, but especially of the future (Kern and Smith 2008; EC 2011, 2013; Bazilian et al. 2013; Lowitzsch et al. 2019; Khan et al. 2020; Nathaniel and Khan 2020; Raimi and Olowo 2021). Certainly, if there were a ranking of the main topics of discussion and concerns on a global scale, energy would be among the top three positions. Discussions on energy issues are numerous and complex: rising global energy demand, growing threats from climate change, growing difficulties and challenges in increasing the share of renewable energy in the overall balance of energy produced, decarbonisation, prices of energy, slow evolution towards energy efficiency, interconnection of energy markets at regional level. This set of themes is complemented, in the case of the European Union (EU), by the increasing dependence on imports (especially oil and gas) which requires decision-making structures to intervene in a dramatic manner, in the sense of proposing and implementing various measures (EU 2009, 2015a).

The future of Europe is closely linked to the energy transition and the broader vision of an economic and social system with a progressive vision of the climate. The European countries have a unique opportunity to transform economic processes in a profound way, to increase the competitiveness and invest in the real economy, and to meet criteria that would help them significantly reduce the greatest risk of this century, global warming. The EU will continue to develop an energy efficient system with a high share of renewable energy. Although renewable energy sources, which are cheaper, play an increasingly important role in the overall energy mix (Dusmanescu et al. 2014; EU 2015b;Voica et al. 2016; Bucur et al. 2021; Ponce and Khan 2021), other energy sources, including natural gas, are still needed when demand is higher.

In the current way of organizing the market, when natural gas is used, its price still determines the total price of electricity, because all producers receive the same price for the same product—electricity. There is a general consensus that the current marginal pricing model is the most effective, but further analysis are needed. The crisis has also drawn attention to the importance of storage for the functioning of the EU natural gas market. The EU currently has a storage capacity of over 20% of its annual gas consumption, but not all EU' member states have specific facilities, and the use of these facilities and the obligations to maintain stocks vary from one member state to another. Additional aspect from the perspective of environmental protection is the need for decarbonization, rather complex and expensive process (Leitão et al. 2021; Shahbaz et al. 2020). The renewable energy is a solution in order to reduce the carbon intensity and to meet *net zero emission* targets proposed by public authorities. For example, the biomethane production is more expensive, but the positive externalities generated by this source must be considered (reduced CO_2 footprint, facilitating the energy transition and territorial development, improvement of energy security), the balance tilts in its favor (Eyl-Mazzega and Mathieu 2020).

The energy sector, both at European and international level, is in the process of transitioning to "green, clean energy", currently reaching a crossroads: on the one hand we are facing the challenge of decarbonizing energy systems, to reduce greenhouse gas emissions and promote renewable sources, and on the other hand, we must ensure the security of electricity supply at an affordable cost to the final consumer. In this regard, at the end of 2019, the EU announced an ambitious program called "Green Deal" to make the EU member states a world leader in combating the effects of climate change and to be the first continent with zero net greenhouse gas emissions in 2050 (EU 2021a). This comprehensive program aims to eliminate fossil fuels, promoting clean energy and developing a circular economy. In this regard, the European Commission aims to allocate funds of around one trillion Euros over the next 10 years (EP 2021a).

2 Energy Transition—General Perspectives

The energy transition generates numerous economic, technical and social challenges (Andrei et al. 2014; Lowitzsch et al. 2019; Morina et al 2021; Shahzad et al. 2021). For this reason, many categories of stakeholders are involved and are interested in the energy transition process. Technical solutions for the use of renewable energy are not always economically efficient, which is why the environmental interests pursued by public authorities must be compatible with the economic interests of companies operating in the energy market and the interests of consumers. This energy transition must be made in such a way as to reduce the impact of energy production and consumption on the environment, but consumers must be protected in view of the price increases that accompany this process. Consumers are important actors in this process because energy poverty affects population in both developed and emerging countries with major differences between urban and rural areas, between men and women (Golpîra and Khan 2019; Feenstra and Clancy 2020; Neacsa et al. 2020) The accessibility of energy for the population is one of the objectives of sustainable development considering the impact it has on the quality of life and health of citizens. Additional ethical challenges are generated by the production of biofuels and bioenergy that involve the use of land and agricultural products not to meet the food needs of the population but to facilitate the process of energy transition (Stancu 2012; Andreea 2018; Ene 2020).

Box 1 Companies—important stakeholder in energy transition

The recent literature highlights that different factors can create competitive advantage, such as, for example, knowledge, reputation, intangible assets, immaterial resources, and the capability to rapidly learn and adjust strategies and tactics (Siano et al. 2011)
Formerly, the focus was mainly on boosting the production and decreasing costs. However, when companies started keeping into account the longer-term perspective, trying to deal with environments in which uncertainty and changes have substituted solidity, these usual factors of competitive advantage were replaced with others that are linked with reaching a sustainable development not only for the organisation but also for the planet and for the entire society (Palazzo et al. 2019). Actually, the growing international awareness about corporate social responsibility (CSR) and sustainability is nowadays requiring firms to embrace sustainable development items and sustainability standards into their strategies, and therefore, to promote the principles of wellbeing, environmental and societal safeguard (Deigh et al. 2016). It has been highlighted that companies which do not succeed in being perceived as sustainable, green or responsible can lose interesting opportunities and can have trouble in strengthening their competitive advantage (Vollero et al. 2016). To emphasize the significance of sustainability, several authors recognized it as a key facet able to create and maintain competitive advantage, along with profitability, positive reputation, and proactive governance (Palazzo 2019; Kantabutra and Ketprapakorn 2020).
In literature, many research on sustainable development investigate whether the financial performance of responsible organisations varies in comparison with other companies that do not follow the sustainability principles (Vollero et al. 2020). There are nevertheless, different opinions on what the possible consequences of actions categorized as 'responsible' on corporate performance are (Palazzo et al. 2020). Even though, it must be said that this concern has critical implications for companies, the environment and the entire society (Foroudi and Palazzo 2021). This is even more true for energy companies. In fact, several studies, in this business field, investigated the difficulties and matters of CSR, highlighting that the key barriers to sustainable development in the social domain are (Amor-Esteban et al. 2019; Lu et al. 2019): inadequate co-operation with publics; ineffective care in motivating human resources; little understanding of the general public about energy companies' activities; and the lack of information about potential damages that can be caused by energy organisations.
In addition, it is important to say that the indicators used to observe the sustainable development of these kind of firms involve both sustainable and energy development indicators. For this reason, this chapter explores the energy sector in which sustainable development is of particular interest, but in which the peculiar context and the link between performance and CSR has not yet been fully analysed.

The term just transition was originally used on the American continent, in the 1990s, when unions set up specific programs for workers who lost their jobs due to environmental protection policies (Teske 2019). However, the energy transition has revealed a multitude of stakeholders who are affected by the passing from fossil fuels to renewable energy use (Dominish et al. 2019; Teske 2019) (Fig. 1).

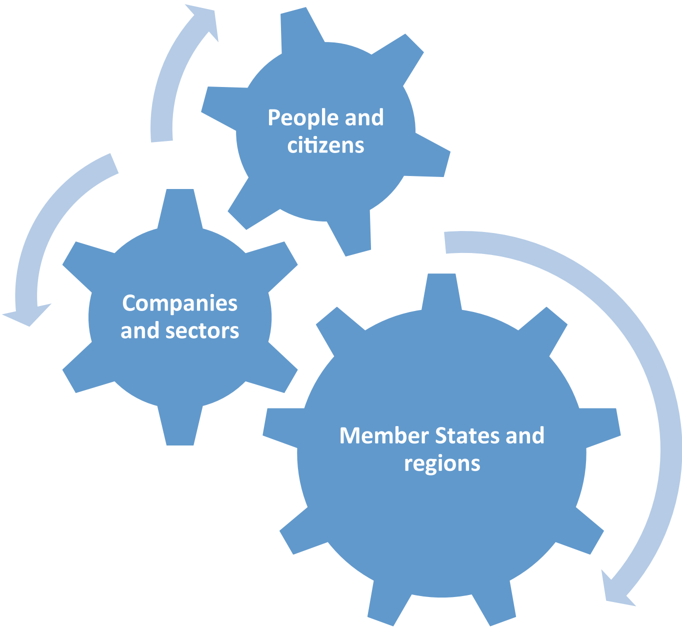

Fig. 1 Actors of just transition mechanism. *Source* The Just Transition Mechanism: making sure no one is left behind | European Commission (europa.eu)

Just Transition Mechanism was set up by the European authorities in order to support regions affected by by the transition towards climate neutrality. Specific financial instruments like Just Transition Fund, InvestEU Just Transition Scheme and Public Sector Loan Facility were created. Public and private funds will be used to finance specific activities like economic diversification and reconversion of the territories affected by transition out of coal, (like Slovakia's Horna Nitra region, Greece's Western Macedonia or Romania's Jiu Valley).

The world's major economies that have adopted renewable energy are, paradoxically, the world's largest polluters: China, followed by the United States (IEA 2020). China is a world leader in clean energy electricity, generating 28.7% of global wind production and 31.9% of global solar production. The US is the second largest producer of both wind and solar energy, generating 21.7% of global wind production and 14.7% of global solar energy production (2018 data).

On the other hand, Germany decided in 2011 to phase out nuclear energy by 2022. Germany has set ambitious targets so that 40–45% of Germany's electricity will come from renewable sources by 2025, by 2035 this percentage will reach 55–60%, and by 2050 to 80%. Specifically, in 2016 alone, in Germany, investments made by companies and private individuals for the development of renewable energies amounted to 15 billion Euros. Later, Germany invested every year, so that the record amount of 31 billion Euros was in 2020 for the creation of new capacities based on wind energy, solar energy and biomass. Based on these investments, the share of green energy in Germany's energy mix increased to 46% of the total in 2020, compared to 43% in 2019.

Other countries have also built energy transition strategies for the use of renewable resources. For example, Poland aims to: (i) reduce the share of coal in energy production from 72 to 56% in 2030, and at least 28% in 2040; (ii) the introduction of offshore wind farms (with capacities of 8–10 GW) in the Baltic Sea and the increase of onshore wind capacity; (iii) construction of the country's first nuclear power plant; (iv) reduction of greenhouse gas emissions by 30% by 2030. Bulgaria instead relies on nuclear energy and photovoltaic power plants by 2030. In addition, Bulgaria aims to increase fivefold the installed capacity for wind energy between 2030 and 2050. In Hungary, it is expected that by 2030 renewable energy production capacity will rise from the current 3 GW to over 7 GW. In 2040 it will exceed 13 GW. The increase will be largely due to new photovoltaic plants.

In the case of Romania, the share of energy from renewable sources in the final gross energy consumption established for 2022 will increase from a share of 27.9% to a share of 30.7%. Regarding the energy sector, Romania aims to cover a share of 50% of its consumption of energy from renewable energy sources by 2030 (Government of Romania 2020). It will be obtained from hydropower, wind energy, solar energy and energy from other sources (e.g. biomass). According to a Deloitte Romania study, 1 billion Euros invested directly in wind farms will generate 2.17 billion Euros in the country's economy, with an additional indirect impact of 2.95 billion Euros in the period 2021–2030. On the other hand, the study shows that the energy transition can bring additional positive effects in construction, transport, energy services, industrial production and the automotive industry (Deloitte Romania 2021).

Another non-polluting and multi-purpose energy source is hydrogen. Hydrogen is the simplest, lightest and most abundant element in the universe. The main advantage of hydrogen is that it can be produced with low or even zero pollutant emissions. For now, green hydrogen production is expensive, but a global cost-cutting technology race is taking shape. Hydrogen can provide a way for Central and Eastern European countries, that depend on coal, to remove their fossil fuel industry (especially Poland and Romania). According to a European Commission study, every billion euros invested in renewable hydrogen creates 10,000 jobs along the supply chain. There are quite a few initiatives in Central and Eastern Europe in the use of hydrogen (Agora Energiewende 2019). Thus, Poland aims to open its first 50 MW cogeneration plant by 2030. This plant is a combination of natural gas and hydrogen that reduces carbon emissions and is seen as a step towards greener energy. Also in Poland, about 300 million Euros have been made available to the authorities for the purchase of 500 hydrogen-powered buses by 2025. Croatia is preparing a national program for the development of the hydrogen market. Slovakia has set up a center for hydrogen technologies. From the perspective of the energy transition process, which Romania has also assumed together with the other EU' member states, the current energy crisis is the moment of truth in the European Green Deal, and the current challenges can be turned into real opportunities, given the imperative of reforms and investments for the competitive functioning of the energy system and for ensuring energy security at national and European level.

3 Energy Transition in Europe—Politically Driven Process

Climate change has generated the concentration of the efforts of international institutions and public authorities in order to find solutions to reduce the negative externalities generated by economic activity (Matthes 2017). One of the most important international legal instruments in the fight against climate change was the Kyoto Protocol (signed in 1997, but become in force in 2005 due to complex ratification process) which set clear individual targets for limiting and reducing greenhouse gases. The main drawback of this protocol was generated by the obligation to reduce greenhouse gas emissions for developed countries, developing countries being exempted from assuming concrete obligations given that countries such as China and India are the world's largest polluters. The developing countries could comply voluntary. In 2015, the United Nations Framework Convention on Climate Change adopted the Paris Agreement, which set out actions to limit global average temperature rise below 2 °C. In addition to these general directions drawn internationally, within the European Union, the concerns about climate change management are complex and involve a mix of economic and social policies that take into account the interests of the stakeholders involved.

The turning point in addressing energy issues was the meeting of the European Council on 24 October 2014, which adopted an **integrated climate and energy policy agenda** (European Council 2014; EC 2015; European Council 2017). The summary content of that document was aimed at achieving a number of objectives by 2030, such as: (i) reduction of greenhouse gas emissions by at least 40% compared to 1990 levels; (ii) increasing by 32% the share of renewable energies in energy consumption; (iii) improving energy efficiency by 32.5%; (iv) interconnection of at least 15% of EU electricity systems.

Another important moment at EU level is the decision of the European Commission, from February 25, 2015, which published the **Strategy on Energy Union** with a view to building an energy union to achieve a secure, sustainable, competitive and affordable energy supply for the all EU inhabitants and socio-economic entities in the EU (EC 2015). According to the document issued, EU energy policy has several major objectives:

- diversifying Europe's energy sources, ensuring energy security through solidarity and cooperation between EU countries;
- promoting research into low-carbon and clean energy technologies and prioritizing research and innovation to drive the energy transition;
- improving energy efficiency and reducing dependence on energy imports, but also reducing emissions;
- decarbonising the economy and transitioning to a low-carbon economy;
- ensuring the functioning of a fully integrated internal energy market, enabling the free movement of energy through the EU by using an appropriate infrastructure.

A fully integrated and properly functioning internal energy market ensures affordable energy prices, transmits the necessary price signals for green energy investments, ensures energy supply and paves the least expensive path to climate neutrality (EC 2016b; EC 2017b). The Energy Union is seen as a vital element in a complex structure of projects needed and useful for the next period, such as the Digital Single Market, the Capital Markets Union or the Investment Plan for Europe (Energy Union 2021). Then, on 30 November 2016, the European Commission proposed the "Clean Energy for All Europeans" package (EC 2016a). Specifically, this package aimed to organize the electricity market and introduced rules on electricity for energy storage and incentives for consumers. A final document of this package was adopted on December 4, 2019 and is related to regulations on the governance of the energy union. To this end, EU Member States need to implement 10-year Integrated *National Energy and Climate Plans (NECPs)* for the period 2021–2030, report every 2 years on progress and develop long-term national strategies. On the other hand, also in 2019, a decision was drawn up at EU level with a view to withdrawing the UK from the EU space for technical adjustments to the projected energy consumption figures for 2030. In addition, in September 2020, the European Commission has adopted the EU Climate Goal Plan for 2030 which aims to update the 2030 target for reducing emissions by 55% compared to 1990 levels (EEA 2020; REMIND 2020). On the other hand, a new meeting of The European Commission aims to develop a new regulatory framework for competitive decarbonised gas markets.

4 Energy Efficiency

Energy efficiency is a "ratio between the result of performance, services, goods or energy and the energy used for this purpose". Energy efficiency is generally based on optimizing consumption, which involves the search for the lowest energy intensity, a "rational use of energy", through more efficient processes and means. Energy efficiency aims to reduce the ecological, economic and social costs induced by energy production, transport and consumption (Worrell et al. 2009; Cooremans 2012). On the other hand, energy efficiency measures mean not only savings in the consumer budget but also a responsible attitude towards the efficient use of resources. For sustainable development, energy efficiency is an important component, because being energy efficient you use fewer resources, but you get the same benefits, whether we are talking about water, heat or electricity. Certainly, energy efficiency measures can help reduce greenhouse gas emissions, help sustainably supply energy, reduce import costs (by reducing the quantities purchased), and support the levels of competitiveness of EU member states.

The document behind the introduction of the concept of energy efficiency was a 2012 EU directive, which set out a set of mandatory measures to help the EU reach its 20% energy efficiency target by 2020 (EU 2012, 2017a). The same directive introduced ambitious targets that are deal with increasing energy efficiency, mandatory energy certificates for buildings, minimum energy efficiency standards for a variety of products, energy efficiency labels and intelligent meters, and the establishment of consumer rights. In December 2018, another directive appeared that updated the EU's overall target for 2030, in order to improve energy efficiency by 32.5% (EU 2018). Then, also in 2018, roadmaps were set with benchmarks for the years 2030, 2040 and 2050 but also long-term strategies for EU countries in order to support the renovation of the national park of residential and non-residential buildings, both public and private. Specifically, it is hoped that by 2050 a decarbonised real estate park with a level of energy efficiency will be generated. In addition to the issues related to the energy performance of buildings, the EU is also interested in cogeneration processes and the energy efficiency of products.

In principle, EU countries have to assess and communicate to the European Commission the potential for high-efficiency cogeneration and central heating and cooling networks in their territory. In addition, an analysis of the costs and benefits of cogeneration in relation to the climatic conditions, economic feasibility and technical adequacy is also mandatory. In relation to the energy efficiency of products, various measures have been proposed: (i) the indication, by labeling and standard product information, of the energy consumption and other resources of energy-related products; (ii) setting ecodesign requirements for energy-related products; (iii) the creation of a new energy labeling framework to define deadlines for the replacement of the current A+, A++ and A+++ energy consumption classes with a scale from A to G.

5 The Current Energy Market

The post-COVID-19 world economy will face new strategic stakes against a pre-pandemic economic status quo. At present, European countries are facing specific challenges of post-pandemic economic recovery. The biggest problem of these years is related to the sharp rise in energy prices in the EU. Therefore, in the medium term, it is necessary to reconfigure the energy sectors and economies in general, but in relation to the objectives of energy security, health security, but also food security. In 2020, the economies of all countries faced for the first time a global crisis caused by health issues, not economic ones. However, energy prices did not change significantly in 2020, the year of the COVID-19 pandemic. In the case of Romania, in the second half of 2020, there were relatively low levels of energy prices for domestic and non-domestic consumers, compared to many EU countries. At the same time, the price of natural gas for household consumers was at the same time the fourth lowest in the EU.

Against the background of the economic recovery in the first half of 2021, in relation to certain specific factors, energy prices are experiencing a rapid and widespread growth in Europe, starting in the middle of this year. At the same time, the US, the Russian Federation and the UK are also facing rising energy prices in 2021, but to a lesser extent compared to what is happening in the EU.

At EU level, the increase in energy prices on wholesale markets is due, in part, to a substantial increase in the price of emission allowances under the EU ETS (EU Emissions Trading Scheme). For example, the price of green certificates has almost doubled in 2021, from 34 euros/tonne of CO_2 at the beginning of January to

63 euros at the end of September. There is therefore a risk that the rising price of energy products will propagate strongly in the coming months. On the other hand, the increase in electricity prices is also a consequence of the increase in natural gas prices from imports, from non-EU sources, mainly from Russia, which thus prepares the ground for the commissioning of the Nord Stream 2 pipeline.

It should be noted that in the European Union, about 20% of electricity production is obtained through natural gas-fired power plants, which means that gas prices determine electricity prices at EU level. To this situation is added the decrease in the production of renewable energy, strictly dependent on weather conditions, in parallel with the reduction of conventional energy capacities (EEA 2020).

With regard to the increase in the price of natural gas as a commodity in EU wholesale markets, the causes include: (i) the restriction by the Russian Federation of the transportation of natural gas through Ukraine; (ii) the reduction of liquefied natural gas (LNG) imports into Europe as a result of the redirection of volumes to Asian markets, amid rising demand from China.

The rise in energy prices at European level has not been uniform or proportionate, but there are differences in dynamics, which are quite pronounced and difficult to explain on a systemic basis. For example, electricity prices in Romania increased in 2021 at a much higher rate than the increase in prices in most EU countries (almost 25% compared to 9.4% in the Eurozone average for August 2021 vs. August 2020). Also, the growth rate of natural gas prices is also quite high compared to last year. For example, Romania ranks 10th among EU countries in terms of rising natural gas prices, with an increase of 20.5% in August 2021 compared to August 2020. Compared, at EU level, consumer prices for natural gas increased by 14.2%.

These sharp upward developments in prices, both for electricity and natural gas, but also for fuel, must necessarily be interpreted in the light of the dependence of European economies on energy imports. This strong dependence of the EU on energy imports, especially from Russia, raises sensitive issues in the field of energy security, hence the need for an integrated strategy at Union level (Röhrkasten and Westphal 2012; Szulecki 2018). Another relevant aspect of the energy market is the dependency ratio in relation to energy independence (Bazilian et al. 2013; Jewell et al. 2016). In this sense, according to the latest available data, for 2019, Romania is on the 3rd place, after Estonia and Sweden, in the top of the energy independence of the EU member states. Certainly Romania is incomparably less dependent on the energy imports that most European countries have to resort to. At the same time, the degree of dependence on energy imports, at the level of the 27 EU states, is very high, of 60.7%, and that of the Eurozone states reaching even 65.3%.

Regarding Romania, despite the delays in the implementation of energy projects, such as the offshore project in the Black Sea or the Iernut power plant, Romania still benefits from some favorable energy conditions: (i) balanced energy mix, with a consistent share of clean energy—hydro and nuclear energy, at least in the current period; (ii) domestic natural gas production, of which about half through the state company Romgaz, with good prospects for increasing production; (iii) electricity imports, although increasing, did not significantly exceed the volumes imported in previous years, according to National Energy Regulatory Authority (ANRE) data.

However, electricity and gas prices have risen in Romania at a faster rate than most EU countries.

Energy prices are in a continuous process of growth, with record levels being recorded as result of the increase of gas prices and green certificate prices and support measures announced by public authorities from several European countries to make bills bearable for final consumers (taking in account the risk of energy poverty which can affect wider sections of the population, with direct consequences on health and living standards). Price increases are generated by rising fossil fuel prices, while costs for renewables production have remained relatively stable. For this reason, the EU is encourage to speed up its energy transition in order to ensure that more citizens have access to cheap renewable energy. In Germany, in mid-September 2021, the price of electricity exceeded for the first time the threshold of 100 euros/MWh, fact generated by rising costs for energy raw materials. In the first half of 2021, coal replaced wind energy as the most important source of energy for electricity production in Germany. In the first six months of 2021, 56% of the 258.9 billion KWh of electricity produced in this country came from conventional energy sources, such as coal, natural gas and nuclear energy, being 20.9% higher than in the first half of 2020. In contrast, the share of renewables, such as energy produced by wind, photovoltaic plants and biogas, decreased by 11.7% in the first six months of 2021, at 44% compared to the same period in 2020. In this country, the natural gas was the third most important source of energy for electricity production after coal and wind energy in the first half of 2021. On the other hand, the lack of wind in Great Britain stimulates the demand for natural gas and pushes up the prices of electricity.

At the same time, record prices for natural gas, recently recorded in Europe, could urgently grant the necessary approvals for the start of gas supplies between Russia and Germany through the Nord Stream 2 pipeline. In early September 2021, the Russian group Gazprom announced the completion of construction work on the Nord Stream 2 gas pipeline, which consists of two separate lines that can annually transport 55 billion cubic meters of gas from Russia to Germany, a sufficient quantity to supply 26 million households. At the TTF gas hub in the Netherlands, prices have exceeded, in recent weeks, more than 670 Euros per 1,000 cubic meters, in the context in which the degree of filling of underground deposits in Europe is below the level of recent years for this period of the year. A measure that will lead to a reduction in natural gas prices is represented by the increase in gas supplies in Europe from Russia (especially through the Gazprom group).

At present, there are countless discussions related to the identification of the causes or factors that led to the increase of energy prices in Romania. An element mentioned as vital is the mechanism of price formation on the wholesale electricity market, which aligns with the less competitive producers, those who produce fossil fuels, in relation to the competitive producers of hydropower and nuclear energy. Therefore, competitive producers, such as Hidroelectrica, Nuclearelectrica and energy producers from renewable sources, end up obtaining "exceptional profits", because their price is not related to their low costs, but to the high costs of coal-based producers (CE Oltenia, CE Hunedoara). In this example, it can be said that there is no competition between technologically different producers. The same situation is encountered on the natural gas market. Thus, the price of imported gas is a benchmark for pricing, especially when consumption is high and domestic production cannot meet demand.

Romania's case has an additional peculiarity as starting with January 1, 2021, the electricity market was liberalized. This liberalization did not in fact only consider changing the contracts for electricity and the electricity supplier, but was based on the elimination of regulations in price formation. Until 2021, the specialized structure called National Energy Regulatory Authority (ANRE) regulated the prices and, possibly, the quantities of electricity sold mainly by Hidroelectrica and Nuclearelectrica. After the elimination of the price regulation by ANRE, there was a need to change the energy supplier by the consumer. This process has also led to paradoxical situations, such as rising energy prices in contracts with the new suppliers.

6 Energy *Spot* Market

The *spot* market is also called the *Next Day Market* (NDM). It is the place where firm hourly transactions are made with electricity, with delivery the day after the day of trading. In other words, the seller and the buyer agree today at a price, negotiated on the spot, depending on more conditions in the coupled regime, and the negotiated quantity is delivered tomorrow, within a certain time interval. Price and quantity are negotiable. In fact, this market works the same as another commodity market, there is supply and demand. In this case, we are dealing with a volatile market, extremely sensitive to changes in consumer demand, whose fluctuations will have an impact on the final price paid by the consumer, domestic or non-domestic.

The increase in prices on the *spot* market led some traders, who had concluded futures contracts to sell energy, at lower prices, to terminate some contracts in order to sell energy at higher prices on the *spot* market. Such speculative behavior of energy producers and energy traders has further boosted electricity prices. The organization of these *spot* energy markets allows the coupling of energy markets with each other. Coupling means that, for the energy that is traded today to be consumed tomorrow, the physical flows "flow" from the markets with the lowest prices to those with the highest prices, in the coupled area. The price coupling of different regions allows spot energy transactions between different countries, in conditions of increased transparency, and offers a trend of price uniformity: energy in cheaper markets will tend to be traded in higher price markets. Each state implicitly allocates border transport capacity, for which no capacity reservation fee is charged, and it is offered directly for trade in energy traded today for consumption tomorrow. Buy orders, as well as sell orders, can come from a "player" on any of the coupled markets, based on an algorithm for pricing throughout the area. During this period (the COVID-19 pandemic period), energy supply in Europe could not keep up with the demand and the rapid rise in prices in the electricity markets, so that after natural gas, coal continues to put countries in a difficult situation.

In Europe, which provides about 20% of its electricity production from natural gas, the switch of some countries to coal due to record gas prices and increased carbon tax rates of up to 65 euros per tonne to limit electricity production from fossil fuels, creates pressures on energy prices. The *spot* price of electricity increased on average by 150% in the first nine months of 2021 on the main European markets. In the United Kingdom, one of the countries where the deepest effects of the energy crisis were observed, the market price of electricity, which was 90 Euro/MWh in January 2021, reached 221 Euro, with an increase of 146% in September 2021. During the same period, the average price of electricity (for 1 MWh) on the German market increased from 52 to 129 Euros with an increase of 148%, in Italy and Spain to 154 Euros from 60 Euros with a increase of 157%, and in France from 60 to 134 Euro with an increase of 123%.

The Romanian *spot* electricity market (the market for the next day) is already coupled in price with those from Hungary, the Czech Republic, Slovakia, Germany, Austria, Poland and Bulgaria. Following the coupling of the Romanian electricity market with the Central European markets, both *futures* and *spot* market prices follow the trend of wholesale prices in those markets, especially those in Germany, Austria, Poland. It should be emphasized that the liberalization of the energy market, which is part of the European commitments assumed by Romania, according to a schedule established by the Law on Electricity and Gas, occurred in this dramatic context of pandemic crisis and during the rising energy prices at European level. In fact, the delayed liberalization of the energy market, in parallel with the use of the regulated price of energy as a protection mechanism, discouraged investment in new production capacity. Thus, an energy deficit with profound implications for energy security has been perpetuated. Therefore, at least in the short term, some measures are needed to prevent abusive market behavior: (i) policies to protect vulnerable consumers, both individuals (households) and industrial; (ii) restoring those market procedures and behaviors that induce deficiencies and amplify discrepancies in energy price dynamics. At the same time, the proposed measures need to be harmonized at European level and brought into line with European legislation, so that common problems at European level can be addressed through converged national solutions that alleviate energy market imbalances.

7 Energy and Energy System in Romania

According to Eurostat data and the energy situation of the 27 member states of the European Union, in 2020 the final energy consumption in households per capita of Romania was 0,416 toe/inhabitant, being 1.33 times lower than the EU-27 average. Romania had one of the lowest final energy consumption in households per capita among the European Union countries (Fig. 2).

In the medium term, the increase in domestic consumption of primary energy and the decrease in domestic production is difficult to be fully covered from renewable sources, which will lead to increased imports (INCP 2020). To demonstrate this idea, contains the energy resources, in structure and by assortment, for the years 2019 and 2020 (Table 1).

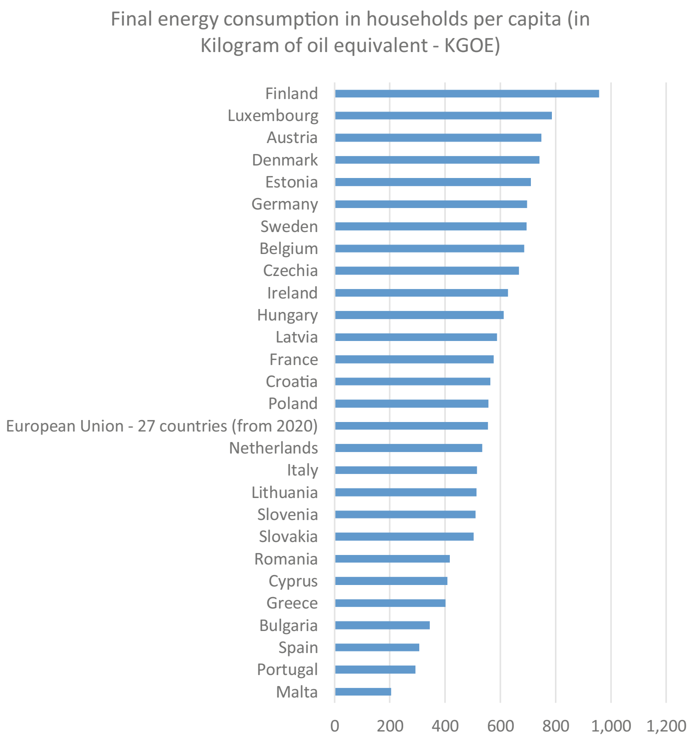

Fig. 2 Final energy consumption in households per capita (Kgoe/inhabitant) in EU-27 countries, in 2020. *Source* Eurostat

The total energy resources available in 2020 registered a decrease of 6.2% compared to 2019. Among the primary energy resources, significant variations were recorded by coal and crude oil resources, which decreased by 31.0%, respectively 12.0%. Primary energy production in 2020, of 22,351 thousand toe, decreased by 2184 thousand toe compared to 2019, amid declining production in all types of primary energy carriers. Another useful information relates to primary energy production in relation to most types of primary energy carriers (see Table 2).

The Romanian energy market is regulated and monitored by the National Energy Regulatory Authority (ANRE). At the time of 01.06.2021 the list of electricity suppliers was composed of: six suppliers of last resort with activity on the retail market, as well (CEZ SA, Enel Energie SA, E. ON Energie Romania SA, ENEL Energie Muntenia SA, Electrica Furnizare SA, Tinmar Energy); 27 energy producers with activity on the retail market, of which the most important are C. E. Oltenia, Electrocentrale Bucureşti, S.P.E.E.H. Hidroelectrica S.A., OMV Petrom S. A., Nuclearelectrica S. A., Petrotel-Lukoil S. A., SNGN Romgaz S. A., Verbund Wind Power Romania; 57 energy suppliers operating in the retail market. On the other hand, the current structure of the Romanian natural gas market currently includes: (i) an operator of the National Transportation System—SNTGN Transgaz S. A. Medias; (ii)

Table 1 Energy resources, in structure and on the main assortments in the period 2019–2020 (thousand toe)

	Year 2019 (thousand toe)	Year 2020 (thousand toe)
Energy resources—total	44,116	41,389
From which:		
– Primary energy production (including recovered energy)	24,535	22,351
– Import	15,910	14,014
– Stock at the beginning of the year	3671	5024
• From primary energy resources:		
– Coal (exclusively coke)	4790	3304
– Crude oil	12,971	11,413
– Usable natural gas	11,546	11,394
– Imported coke	501	419
– Imported petroleum products	3263	3507
– Hydroelectric, wind, solar photovoltaic and nuclear power	4960	4986

Source Romanian national institute of statistics

Table 2 Production of the main primary energy carriers in the period 2019–2020

	Year 2019 (thousand toe)	Year 2020 (thousand toe)
– Coal (exclusively coke);	3928	2592
– Crude oil	3490	3382
– Usable natural gas	8274	7391
– Hydroelectric, wind and solar photovoltaic energy	2114	2099

Source Romanian national institute of statistics

six producers: Petrom, Romgaz, Amromco, Toreador, Wintershall Medias, Aurelian Oil ānd Gas; (iii) three operators for underground storage depots: Romgaz, Amgaz, Depomures; (iv) 34 natural gas distribution and supply companies to the captive consumers—the largest being Distrigaz Sud and E.ON Gaz Romania; 76 suppliers on the wholesale market.

Almost 99% of the 5.9 million consumers (mostly households) received energy from seven companies: CEZ Vânzare SA, Electrica Furnizare SA, E.ON Energie România SA, Enel Energie SA, Enel Energie Muntenia SA, Engie România SA and Tinmar Energy SA, as it appears from the ANRE reports. RCS & RDS, another newer player in the energy market, reportedly had nearly 150,000 subscribers at the end of last year. In order to have a clearer picture of the most powerful and influential

Table 3 Info data for the most important energy and gas companies from Romania (2020)

No	Company	Annual turnover -billion Euro-	Profit -million Euro-	Number of employees	Product (commodity)	Shareholders
1	CEZ Vânzare SA	0.4	9.4	242	Electricity and gas	99.999999% Felix Supply Holdings SRL Bucharest + Felix Powe Holdings SARL
2	ENEL Energie SA Bucharest	0.56	27.4	250	Electricity and gas	51.003% Enel SPA, 36.997% Energy Participants Management Company, 12% "Proprietatea" Fund
3	E.ON Energie România SA	0.84	−0.84	172	Electricity and gas	68,18% E.ON România SRL, 31.82%. Ministry of Energy
4	ENEL Energie Muntenia SA Bucharest	0.56	27.8	271	Electricity and gas	78% Enel SPA, 12% "Proprietatea" Fund, 10% Energy Participants Management Company
5	Electrica Furnizare SA Bucharest	1.02	46.6	781	Electricity and gas	99.999842% Societatea Energetică SA + Societatea Filială de Întreținere și Servicii Energetice „Electrica Serv"
6	Hidroelectrica SA Bucharest	0.76	290	3354	Electricity	80,0561% Ministry of Energy, 19,9439% "Proprietatea" Fund
7	OMV Petrom SA	2.96	280	10,949	Electricity and gas	51,0105% OMV AktienGesellShaft, 20,6389% Ministry of Energy, 9,9985% "Proprietatea" Fund
8	Nuclearelectrica SA	0.48	139.8	2028	Electricity	82,4981% Ministry of Energy, 7,0539% "Proprietatea" Fund, 10,45% other shareholders

(continued)

Table 3 (continued)

No	Company	Annual turnover -billion Euro-	Profit -million Euro-	Number of employees	Product (commodity)	Shareholders
9	Tinmar Energy SA	0.44	22.4	90	Electricity and gas	63,283,789% JO Holding AG Switzerland, 20,86,025% Victory Executive SRL Bucharest, 15,855,961% Martin Oil Energy SRL
10	Engie Romania SA	1.3	99.6	753	Electricity and gas	50,994,702% Romania Gas Holding BV Nederland, 36,996,161% Ministry of Energy, 11,998,753% "Proprietatea" Fund
11	RCS&RDS SA	0.78	48.6	13,056	Electricity	Digi Communications NV
12	Complexul Energetic Oltenia SA	0.42	−196	12,193	Electricity	77.151383% Ministry of Energy, 21.559907% "Proprietatea" Fund, 1,28,871% other shareholders

Source authors based on companies public information

producers and distributors on the Romanian energy and gas market, Table 3 presents the most important and new information about 12 such companies.

At present, Romania has a balanced and diversified mix of primary energy resources in energy production. For example, in 2017, the share of primary energy resources in energy production had the following structure: energy produced from coal 27.5% (17.3 TWh); energy produced in hydroelectric power plants 23% (14.4 TWh); energy produced in the Cernavoda nuclear power plant 18.3% (11.5 TWh); energy produced on hydrocarbons (oil and gas) 17% (10.7 TWh); energy produced in wind and photovoltaic installations 13.5% (8.5 TWh), energy produced from biomass 0.7% (0.4 TWh).

In 2020, the energy production in Romania came from wind energy in proportion of 12.4%, 3.4% from photovoltaic solar panels, while 27.6% of energy production came from hydropower. In total, the production of renewable energy (wind, photovoltaic and biomass) accounted for 16% of the total, while energy from nuclear sources reached a percentage of 21%. A significant percentage decrease was recorded by the production of energy generated from coal, with a level of about 17% (NRRP 2021). At the beginning of November 2021, Romania's energy mix was represented as follows: 21.44% (hydrocarbons); 21.28% (coal); 20.57% (nuclear); 19.21% (hydro); 16.65% (wind); 0.85% (biomass). It can be said that this representation of energy sources once again demonstrates a good balance and diversification in energy production. For 2030, it is proposed to increase the share of energy from nuclear sources to 17.4 TWh, and in 2035–23.2 TWh. An increase to 29TWh will be recorded in total renewable sources, representing a share of 37.9% of the total primary energy sources that will make up the energy mix in 2030. Energy produced from coal will register a slight decrease to 15.8TWh and will had a share of 20.6%. An increase of 1.9% will record the production of energy from hydrocarbons (especially gas) at approx. 14.5 TWh [19, 23].

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8 Energy Security in Europe and in Romania

In the face of a potential danger, namely the emergence of a global power outage at European level, the EU institutions must be concerned with ensuring the security of energy supply of all member states. In this regard, the EU has in recent years developed important directives and regulations:

- Regulation (EU) 2019/941, a regulation on risk preparedness in the energy sector which requires EU member states to cooperate in order to ensure that, in the event of an energy crisis, electricity reaches where it is most needed of it;
- Directive (EU) 2019/692, which certifies that the rules governing the EU internal gas market apply to gas transportation lines between a member state and a third country, with derogations for existing pipelines;
- Regulation (EU) 2017/1938, a regulation on security of natural gas supply, which introduced guarantees on security of natural gas and strengthened mechanisms for prevention, solidarity and response in crisis situations; this regulation provides for the strengthening of regional cooperation, preventive action plans and regional contingency plans and a solidarity mechanism to ensure security of gas supply;
- Directive 2009/119/ EC, EU Directive on crude oil stocks, whereby member states must maintain minimum oil reserves corresponding to either the daily average of 90-day net imports or the 61-day daily average of domestic consumption, depending on which quantity is higher;
- Directive 2009/73/ EC, Gas Directive, with a view to including gas pipelines to and from third countries, including existing and future pipelines.

What exactly is wanted for energy security? There are at least three general measures of action: (i) diversification of production sources and reduction of dependence on imports; (ii) ensuring the adequacy and flexibility of the energy system; (iii) preventing and managing the risks of power outages.

In addition, to ensure the security of energy supply throughout the EU, the energy infrastructure of EU countries is included in the TEN-E policy, which identifies nine priority corridors (four electricity corridors, four gas corridors and one crude oil corridor), and three priority thematic areas (smart grids, electricity highways, cross-border carbon dioxide networks) to develop better connected energy networks in the EU.

What is happening now in the gas and energy markets is a wake-up call at European level, which must have a strong echo at the strategic level of policy decisions in this area. This post-pandemic energy context calls into question the EU's position on the map of economic competitiveness and energy security. Following the sharp rise in energy prices, amid the assumption of the most ambitious green transition targets and sustainable development goals, through European environmental policies, the Union's economic competitiveness will suffer greatly in the global competition. Against the background of rising and maintaining high energy prices, Europe's strongest industries could end up relocating or investing in new production capacity outside the EU.

This moment can be considered a T_0 moment in the field of energy, a moment that represents for the EU countries the moment of reconfiguring the calendar and the objectives of green transition, in which is necessary to analyze the policy of green certificates, in the sense of supporting to maintain and improve the competitiveness of industries from Europe.

Romania aims to maintain a diversified energy mix by 2030, taking into account the decarbonization objective of the energy system (NRRP 2021). In order to ensure energy security at national level, Romania has taken or is committed (including in the National Recovery and Resilience Plan) to take measures for the implementation of several projects in terms of resource diversification, namely:

- prompt implementation of the legal framework necessary for final investment decisions in the exploitation of natural gas resources in the Black Sea area;
- adoption of the decarbonization plan proposed by the Oltenia Energy Complex (Complexul Energetic Oltenia SA), the main producer of coal-based electricity—in order to ensure a sustainable transition to a low-carbon energy production;
- diversification of uranium sources for Nuclearelectrica;
- extending the duration of operation and building new nuclear capabilities;
- development of new capacities on RES (renewable energy sources) and integration with other markets in the region as well as promoting the use of hydrogen;
- development/optimization of the existing infrastructure of energy and natural gas networks, with a positive impact on the capacity to take over the energy produced from renewable energy resources and on the level of interconnectivity;
- development of storage capacities.

Energy transportation corridors also include regional natural gas initiatives. These "highways" have an operational, commercial and especially strategic impact, ensuring a high degree of energy security for Romania and other neighbouring states (NRRP 2021):

- The BRUA corridor transits Bulgaria, Romania, Hungary and Austria with a direct impact on the energy systems of these member countries;
- The Southern Transport Corridor for which the transportation operator intends to access European funds and which would bring the gases extracted from the Black Sea into the BRUA highway with an impact on the countries mentioned above;
- The project "Developments of SNT (National Natural Gas Transportation System) in the North East area of Romania" which is part of priority axis 8 and aims to ensure transport capacity from/to the Republic of Moldova;
- The project "Interconnection of the national natural gas transportation system with the international natural gas transmission pipeline T1 and Isaccea reverse flow" included as part of the NSI East priority corridor with impact on the energy system in Romania and Ukraine;
- Interconnection of the National Natural Gas Transportation System in Romania with the natural gas transportation system in Serbia that will ensure energy security, development of energy infrastructure by diversifying energy transmission sources and routes, strengthening solidarity between member states and ensuring the efficient functioning of the energy market;
- Interconnection of the national natural gas transportation system with the natural gas transportation system in Ukraine, in the direction of Gherăești-Siret, which implies increasing the degree of interconnection of the national natural gas transportation network with the European transportation network.

9 Conclusions

Certainly, if there were a ranking of the main topics of discussion and concerns on a global scale, energy would be among the top three positions Because energy and the energy sector are the fulcrum of everything that happens in the society and in the entire universe, constant concerns for how to create, manage and keep energy is a main priority for public authorities and companies. Therefore, the aim of the chapter was to highlight that knowing and informing the public opinion about how energy issues are handled by different authorities can help to the understand and solve difficult situations that people may face in the near or distant future. The efforts of the European authorities to facilitate the energy transition are remarkable, the involvement of the member countries being special by setting specific targets and objectives and adopting concerted measures adapted to the national situation. However, the energy transition cannot be achieved without the involvement of consumers and companies that need to understand the role played in the process of saving and rationally consuming energy. Energy companies are the main actors in this process, adapting their business strategies to meet the new requirements imposed by the energy transition.

Taking in account the analyse made, it is clear that this work can offer contributions and has several implications. Referring to theoretical implications, the chapter can help researchers in identifying in the literature new reasons that can push companies, in the energy sector, to embrace CSR and set the bases for fostering sustainable development. In fact, this strategy can aid organisations in reaching several benefits, such as: good corporate reputation, building trust and increased customer loyalty. At the same time, taking the managerial contributions into account, the chapter can present some inputs to promote the growth of the diffusion of more sophisticated CSR procedures in the energy sector. Nevertheless, more qualitative and quantitative data are needed in order to enrich the perspective that is briefly outlined in this work. Indeed, other cases would need to be examined. In particular, other companies taken from other segments of this wide sector have to be analysed to achieve a more complete overview of the issue.

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