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CONSTENTS

Understanding government policies on renewable energy deployment and climate change mitigation in Nigeria since the russia-ukraine crisis

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Abstract: The global energy sector remains affected by the Russian-Ukraine crisis. Prior to the crisis, the United Nation Sustainable Development Goals (SDGs) has energy transition plan from fossil fuel to renewable sources, a measure aimed at addressing climate change by the year 2030. However, while the Russian-Ukraine belligerent relationship was not predicted, it has served as a catalyst for energy transition across the world given the increase in the price of fossil fuel. The study addressed the question; Is the effect of Russia-Ukraine crisis on fossil fuel accessibility enhancing renewable energy deployment in electricity generation in Nigeria? The study analyzed how the effect of Russia-Ukraine crisis on fossil fuel accessibility in enhancing renewable energy deployment in electricity generation in Nigeria. The underlying assumption of the study is that the Russia-Ukraine crisis will not catalyze the transition of electricity generation from fossil fuel to renewable sources in Nigeria. The theoretical framework of the study is public choice theory and it is applied from the perspective that government instrument instead of market force allocate certain need. The study adopted descriptive research design and Nigeria transition to renewable energy was case studied. Information were obtained from purposively selected government documents and website pages of concerned agencies. Information gathered were content analyzed. The study noted that electrical energy continued to be sourced from non-renewable sources in the country despite the extant policies of government on transition to renewable energy in the country. The study concluded that politics rather than emergency situation drives energy transition.

Key words: Climate Change, Electrical Energy, Fossil Fuel, Russia-Ukraine Crisis, Nigeria

Introduction

Prior to and since the outbreak of the Russia-Ukraine crisis, access to fossil fuel has remain problematic for importing economies, a class to which Nigeria belong. The crisis is expected to impact world population, economy, energy use, as well as climate despite the United Nations' Sustainable Development Goals, SDG (Martinho, 2022; Pereira, Zhao, Symochko, Inacio, Bogunovic, & Barcelo, 2022; Prins, 2022). The implementation of the SDG is arguably under threat both to the belligerent states and economies around the world as a result of escalation (Pereira et al., 2022). Also, the crisis is expected to affect the forest sector in that both rural and urban dwellers in states in the international system confronted with shortage of electrical energy may result to the use of fuelwood as a source of cooking energy (Prins, 2022; Pelz, Chinchian, Neyrand, & Blechinger, 2023). While Fueki et al (cited in Omotosho, 2019) identified the impact of oil shocks on domestic and global economies due to the absence of substitute, sanctions placed by the European Union, EU, alongside other western states, on the Russian economy, following the invasion of Ukraine, resulted in increase in the price of energy and welfare cost, and engendered energy crisis in the Euro zone, and in states in the international system including Nigeria (Hausmann et al., 2022; Perdana, Vielle, & Schenckery, 2022; Falahi, 2022). Guan et al. (2023) remarked that the war ignited an energy crisis against households capable of increasing the cost of energy accessed by them to about 62.6-112 per cent globally and pushing the number of poor households to about 78-141 million across the world.

Addressing the associated challenges of energy crisis resulting from the Russia-Ukraine crisis has encouraged increase in the use of coal in the Eurozone for the generation of electricity, which is with implications for the implementation of the EU plan on the reduction in the Greenhouse Gas Emissions (Perdana et al., 2022). Also, the quest to mitigate the environmental implications of engaging non-renewable sources informed the increase in budgetary allocation for the development of renewable energy technology and facing-out dependence on gas and oil from Russia (Saktiawan, Toro, & Saputro, 2022; LaBelle, 2023). Whereas in Ghana prior to the war, renewable energy constituted about 1 per cent of the electrical mix with projected increase to about 10 per cent by 2030, vehicular movement depends on fossil fuel (Osei-Tutu, Boadi, & Kusi-Kvei, 2021). Furthermore, Isha et al (2023) has demonstrated how policy challenges confronting energy firm could impact energy transition in medium and low countries with evidence from Brazil and Nigeria. It was revealed that through innovative policies Brazil has been able to facilitate transition to renewable energy whereas in Nigeria, uncertainty in policy and finance has hindered investment in energy transition (Isha et al., 2023). The outcome of this is the continuous reliance on non-renewable energy sources in Nigeria.

Specifically, while Nigeria is an exporter of crude oil, large quantity of the product is imported such that between 2010 and 2018, fossil fuel represented about 93.1 per cent of the aggregate export of Nigeria while the same amounted to about 24.4 per cent of the country's import (Oguntunde, Oguntunde, Ojo, & Okagbue, 2018; Omotosho, 2019). The importation of crude oil in Nigeria is due to inadequate government investment in the oil sector, and poor state of refineries (Monday, Obi & Udo, 2018). Hence, following the collapse of local refineries in Nigeria, in the late 1980, the countries has become exposed to the fluctuations of oil price because it imports refined crude oil (Obioma cited in Monday et al., 2018; Oguntunde et al., 2018). The above explains the reasons for the subjection of Nigerian energy sector to fluctuation in fossil fuel accessibility in the international market and the recurrence of energy crisis in the country. Notably, as the price of fossil fuels continues to soar in the international market, households also switch to alternative sources of energy such as fuelwood and charcoal for cooking (Eniola, 2021; James, 2022; Oyediji & Adenika, 2022; Pelz et al., 2023). It was estimated that over 30 million households sourced for cooking energy from fuel wood in Nigeria (Pelz et al., 2023). These sources are not renewable and are with implications for the health and environment of dwellers because it allows for environmental degradations, pollution, and global warming.

It is useful to note that there is interdependence and interconnections between electrical energy security and climate because electrical energy is crucial to the economic and social life of every state (Debebe et al., 2023; Kicaj et al., 2023). In fact, foreign policy, national interest, support for democracy, economic development, reduction in poverty, and protection of the environment revolve around energy (Bovan, Vucenovic, & Peric, 2020; LaBelle, 2023). Also, the production of goods and services, information dissemination, and economic development is achievable through energy (Albert, 2021; Chudy-Laskowska, & Pisula, 2022). While electrical energy remains crucial to the life of any state, it is usually generated from non-renewable sources, such as fossil fuel, and this explains the nexus between the generation of electricity from non-renewable sources and other sectors of the economy (Inegbdion, inegbedion, Obadiaru, & Asaleye, 2020; Chudy-Laskowska, & Pisula, 2022). The non-renewable energy sources used across countries has included gas-fired, oil powered, through coal powered (Chudy-Laskowska & Pisula, 2022; Debebe et al., 2023). Of these sources of non-renewable energy generation, hydro and gas fired have taken preference overtime in Nigeria (Agbo et al., 2021; Soyemi, Samuel, Adesanya, Akinmeji, & Adenuga, 2021). It was reported that about 79 per cent of the electricity need of Nigeria were generated from fossil fuel (Agbo et al., 2021). Hence, inaccessibility to fossil fuel in the international market significantly affects electrical energy availability for use in the country.

Hence, despite the importance of electrical energy and issues with its accessibility in Nigeria, Pelz et al. (2023) claimed that while states are embarking on energy transition from non-renewable to renewable sources with the aim of achieving the SDGs 7, limited data on energy accessibility remain a challenge in Nigeria's energy transition plan. Hence, while Obafemi et al. (2018) claimed that about 40 per cent of the population connected to the national grid does not have adequate access to electrical energy need, the WorldBank (cited in Pelz et al., 2023) estimated electricity accessibility in Nigeria at 55.4 per cent, and noted that there is a wide gap of accessibility between the Urban and Rural population at 83.9 to 24.6 per cent respectively. Also, the irregular supply vis-à-vis outright absence of electricity supply in Nigerian communities have prompted the adoption of fossil-fueled self-electrical energy generating set both by households and businesses as a means of achieving their routine electrical energy need (Chanchangi et al., 2021) and also with implications for climate change. Thus, while there is increasing awareness for the use of renewable energy, fossil fuel is still been traded. The reason for this has been presented from two major perspectives which are energy politics (Agbo et al., 2021) and the level of technological development (Caineng, Qun, Guosheng, & Bo, 2016).

Whilst Caineng et al (2016) posited that the development of eco-friendly technology will solve the pollution problem identified with fossil fuel through replacement, Agbo et al. (2021) noted that the decision of petroleum producing states to ensure the growth of their Gross Domestic Product, GDP, encourages the selling of their fossil fuel in the international market. While Nigeria being an exporter and importer of fossil fuel continue to experience energy crisis resulting from external pressure such as Russia-Ukraine crisis, households continue to source for alternatives in the form of fuelwood in attaining their routine cooking energy needs and these sources are with implications for the environment and health of dweller. Ren, Liu, Li, and Zang (2022) affirmed the above and noted that the deployment of non-renewable energy such as charcoal and wood negatively impacts residents' life contentment because it affects their health, and the increasing use of such sources will pitch dwellers into 'environmental-health-trap'.

Thus, while the price of fossil fuel continues to soar in the international market and electrical energy remain inaccessible to majority across the world, Ugwu et al. (2022) identified the low level of renewable energy technological development in the country with poor research, issues of finance, and poor execution of renewable energy policies. In fact, the escalation of the Russia-Ukraine crisis and raising electrical energy inaccessibility occasioned by fossil fuel supply shortage to states in the international system, have prompted states transition to renewable energy sources (Saktiawan et al., 2022; Ugwu et al, 2022; LaBelle, 2023) and with the possibility of climate change mitigation. However, it remains unclear how the Nigerian government will adhere to the SDG provisions on the generation of clean energy from renewable sources using renewable energy technology when the country earned its foreign exchange from fossil fuel (Oguntunde et al., 2018; Omotosho, 2019; Agbo et al., 2021). The study is conducted against this background, hence this study.

The study addressed the question; Is the effect of Russia-Ukraine crisis on fossil fuel accessibility enhancing renewable energy deployment in electricity generation in Nigeria? The study analyzed how the effect of Russia-Ukraine crisis on fossil fuel accessibility is enhancing renewable energy deployment in electricity generation in Nigeria. The underlying assumption of the study is that the Russia-Ukraine crisis will not catalyze the transition of electricity generation from fossil fuel to renewable sources in Nigeria.

The study in achieving its stated objectives has five sections. The introduction formed the content of section one. In section two, there is the discussion of literature review. Methodology of the study was discussed in section three. Presentation of finding and discussion was done in section four. The study was concluded in section five.

Literature Review

This section presents the reviewed extant studies under three sub-headings including; conceptualization, theoretical framework, and empirical review.

Conceptualization of Climate Change

Climate change implies increase in global temperature (Kaddo, 2016; Olagunju, Adewoye, Adewoye, & Opasola, 2021). Kaddo (2016) quoted the NASA observation that the earth temperature has increased by one degree. McMichael et al (nd) argued that based on the available evidence, the world climate is changing through human activities especially the release of greenhouse gases from fossil fuel. It was noted that precisely from 1976, the global temperature has increased by 0.6 to 0.2^{o}C (McMichael et al., nd). Olagunju et al (2021) explained the term climate change as obvious alteration to the condition of the climate and its properties over the period of a decade or more. Hence, biogeographical and anthropogenic factors have been identified as the two major factors responsible for changes in the climatic conditions (Olagunju et al., 2021). In this study, the concept of climate change is explained according to the definitions of Kaddo (2016) and Olagunju et al (2021). The reason is because the two definitions recognized climate change has upward changes in the global temperature which is observable over a minimum of a decade or more.

Theoretical Framework

Public choice theory is adopted for the study from Ostrom (1975) and Feldman (1986) point of views. Ostrom (1975) noted that the nonmarket decision is the major concern of public choice theory. Thus, the limitation of the market in allocating resources effectively and efficiently as been recognized by economist, as such, there are goods and services which are better made available by the government through its instrumentality (Ostrom, 1975). Renewable energy belongs to such class after all the policy of government better ensures compliance with the use of the technology and its availability to member of the public. The public choice theory has been paraphrased by Feldman (1986) as the availability and use of natural resources informed by the level of development and conditioned by costs and benefits. Also, the form of resources and its availability dictates resources management (Feldman, 1986). Hence, the theory, because it allows for the examination of the nexus between natural resources and policies of government is adopted for this study.

Empirical Review

This section presents reviews of extant studies under the outlined themes.

A Review of Global Energy Transition to Renewable Sources Since Russia-Ukraine

The Russia-Ukraine crisis, following the effect of the Covid-19 on energy market, is one of the factors catalyzing the transition to renewable energy across the world (Guan et al., 2023). Albert (2022) as noted the effect of Covid-19 on energy source and use to include continuous deployment of renewable energy technology as a substitute to fossil fuel. Of course, Russia is a major supplier of fossil fuel across the world with the contribution of about 12.3 per cent of oil and 23.6 per cent of natural gas globally in the year 2021, and since the outbreak of the war, price of energy continues to soar in the international energy market (Guan et al., 2023) and this is resulting in energy poverty for households in the international system (Ren et al., 2022). Energy poverty has been presented as the inaccessibility of clean source of energy by households (Ren et al., 2022).

Before the outbreak of Covid-19 and the Russia-Ukraine war, renewable energy technology has continued to be deployed. Kuzemko et al (2020) explained the factors driving the deployment with the sharp decline in the price of renewable energy technology. As such, energy is expected to be sourced from solar, wind, biofuel, and biomass, and these sources will not be conditioned by the fluctuations in the fossil fuel market and it will enhance reduction in the emission of greenhouse gases (Chudy-Laskowska & Pisula, 2022), and solve energy poverty issues (Ren et al., 2022). The deployment of renewable energy technology is in fulfilment of the SDGs goal on climate change mitigation, a reality which is identified with the engagement of renewable energy technology as alternative to fossil fuel as source of energy.

However, the aggressive deployment of renewable energy technology in solving energy issues across the globe has been confronted with challenges including the capability of serving as the absolute replacement to fossil fuel (Breetz, Mildenberger, & Stokes, 2018; Albert, 2022). Energy transition, especially from fossil fuel to renewable sources, is believed to be conditioned by factors inclusive of cost of technology, rate of deployment, and politics (Breetz et al, 2018). The hidden factor conditioning the adoption and deployment of energy technology has been identified as politics, and this is because the political institution and condition that encourage the growth of a new technology differs absolutely from the condition that ensures the replacement of the extant technology (Breetz et al., 2018).

Hence, while there is aggressive campaign for the adoption of renewable energy across the world, the policy of countries remains crucial to its adoption and implementation. Albert (2022) has attested to the claim and stated that it is not possible to transit to fossil fuel absolutely with the 'non-substitutability hypothesis'. It was argued that though majority of the International Political Economy scholars posited that fossil fuel will be absolutely substituted by renewable energy and the level of growth will remain the same (Albert, 2022). On the contrary, the complete transition to renewable energy especially with the target of full decarbonization of the world will be achievable only with 'great transformation' or structural changes (Albert, 2022), in countries across the world. This is with cost implications and sustainability concerns for countries in the international system.

Household Energy Choice and Climate Change Concerns in Developing Countries'

The quantity of energy used by households across the world accounts for a major percentage of the total energy consumption (Ren et al., 2022). Hence globally, cooking, heating, cooling, and transportation are forms of household energy consumption in any economy (Danlami, Islam, & Applanaidu, 2015; Ren et al., 2022). Households obtained energy from fossil fuels and renewable sources (Lyakurwa & Mkuna, 2019). This is because energy is one of the routinely required elements by human being for its survival (Danlami et al., 2015; Caineng et al., 2016). More so, Danlami et al (2015) outlined energy sources available to households to include electricity, gas, petroleum, solar, and kerosene. After all, energy consumption by household has been describe as energy resources used by a household on appliances (Danlami et al., 2015).

Whilst studies have presented the quest for clean and afford energy by household in developing countries has a problem (Jan, Khan, & Hayat, 2011; Ren et al., 2022), Covert et al., (2016) noted that in developing countries there are few policies on the use of fossil fuel despite the raising cases of air pollution. In fact, Debebe et al (2023) pointed out that ensuring energy security and containing the contribution of energy use to environmental changes remain a source of concern in most African states because of the continuous reliance of about 900 million households on the use of biomass fuel for cooking. Hence, the question continued to be asked on potential factors responsible for the use of non-renewable sources against renewable sources of energy.

Aina and Odebiyi (1998) using the energy consumption classified the Nigerian economy into five sector which are households, agricultural, commercial, transport, and industries. Of these sectors, the household was noted to consume energy more than the other sectors. Thus, in the country, fuelwood has been identified as supplying 80 per cent of the energy need of households (Eniola, 2021; James, 2022; Oyediji & Adenika, 2022; Pelz et al., 2023). This demonstrated energy challenge recorded in the country, and addressing this has informed the demand by Oyedepo (2012) for diversifies sources of energy for commercial, industrial, and domestic with the adoption of new technologies. However, energy accessibility remains an issue in Nigeria (Agbo et al., 2021).

Jan et al (2011) analyzed energy choice determinant of rural household in Pakistan and noted that while there exist diverse energy sources to households, there is preference for biomass fuels. Also, while factors determining energy choice has included availability of alternatives sources of energy, and energy preference, income is noted to be the key determinant. Danlami et al (2015) outlined factors such as number of residents, age, income, nature of employment, residence location (urban/rural) as factors informing energy choice. In a review by Ateba, Prinsloo, and Fourie (2018) on the effects of choice of energy and determinants on the use of energy in selected South African households, it was noted that factors including irregular supply of electricity is responsible for the use of other fuel especially by the low-income households.

Lyakurwa and Mkuna (2019) in their interrogation of dominant choice of energy by households in Tanzania, identified household income as a major factor determining sources of energy. In fact, it was evident in their interrogation that household utilization of renewable energy for cooking, lighting, and heating was low. Similarly, Debebe et al (2023) in their discussion on the household energy choice determinant for domestic chore in Ethiopia revealed that the utilization of energy is skewed towards fuels from biomass, specifically fuelwood, and charcoal. About 87 per cent of the sampled population uses fuelwood, 32 per cent uses charcoal, and 17 per cent utilizes electricity for domestic activities (Debebe et al., 2023). Hence, flowing from Mukhadi, Machate, and Semenya (2021) empirical review of energy choice and consumption from 32 countries energy sources has been identified to include fuelwood, gas, charcoal, and kerosene. It was noted in the study that choice of energy was conditioned by demographic, economic status, (rural/urban) location, and level of education. It is obvious from the above that the use of energy is vital and the condition to use it is responsible for choice sources among dwellers in particular location. Hence, mitigating the impact of fossil fuel is more informed by government policies.

Materials and Methodology

The methodology of the study was presented in this section. This section presented the research design, sampling method, and data collection and analysis.

Research Design (RD)

The RD for the study was descriptive and Nigeria was case studied on renewable energy technology deployment. Relevant information was sourced from secondary materials including government documents and agencies of government website. The essence of adopting descriptive RD is due to its capability to provide explanation to issues, events, policies, and programme (Dulock, 1993; Kumar, 2011; Hassan, 2022[1]). This is suitable to the research because the central objective of the study was to provide understanding to the policies of government on RE deployment and climate change mitigation since the Russia-Ukraine crisis. After all, since the year 2015, climate change mitigation through energy transition from fossil fuel to renewable sources has formed the cornerstone of global goals with the aim of protecting the earth[2]. Hence, the study purposively selected the rules and regulations, and policies enacted on such effect in Nigeria. Hence, the National Climate Change Policy for Nigeria for 2021-2030, and the Climate Change Act of 2021were selected for review, and these constituted the secondary data. Evaluating the level of implementation, especially since the Russia-Ukraine crisis, also informed the selection and review of the Nigeria Energy Transition Plan, NETP[3] and the National Electricity Regulation Commission, NERC[4] using purposive sampling technique. Information gathered were analyzed using content analysis.

Findings

This section presents the information gathered on the outline objectives and based on the methodology discussed.

[1] This was retrieved from www.researchmethod.net/descriptive-research-design/#How_to_Conduct_Descriptive_Research_Design
[2] This was retrieved from https://www.undp.org/sustainable-development-goals on the 12th of August, 2023
[3] www.energytransition.gov.ng
[4] https://nerc.gov.ng/index.php/home/nesi/403-generation#

Renewable Energy Deployment in Electricity Generation in Nigeria Since the Russia-Ukraine Crisis

The signing of the Paris Agreement of 2015 by Nigeria in 2017 signifies the readiness of the country to promote the transition of energy generation to the adoption of low carbon technology[5] or renewable energy technology. Specifically, section 19(1) of the Climate Change Act of Nigeria[6] obliged the Ministry of Environment to act in line with the international guideline on energy generation, that is the SDG with concerns for climate change action plan, and

> set the carbon budget for the country, preserve the increase in global temperature within 2^{o}C, and adopt measures to restrict the increase in temperature to 1.5^{o}C above the pre-industrial level

The policy action itemized in the National Climate Change Policy on energy for Nigeria 2021-2030 for the accomplishment of the set target, in accordance with international standard, has included[7]

> the deployment of renewable energy such as solar and wind, enhance efficient energy use and management through the adoption of new and innovative techniques of generation of power and introduction of innovative technology; production and use both in on-grid and off-grid; enhance full transition to clean cooking fuel, contain transmission and distribution losses; encourage cities to ambitiously use climate change mitigation actions; avail financial and sustainable support for the use of renewable energy sources

As such, available information on the website of Nigeria Energy Transition Plan[8] revealed that the Energy Transition Plan, ETP, has been endorsed by the Federal Executive Council[9] and a working committee on implementation has been commissioned (and the main member includes the foreign affair ministry, finance, environment, power, work, and housing)[10]. Also, support has been received by the working group from the Sustainable Energy for All, and the Global Energy Alliance for People and Planet[11]. To accomplish it essence, the working group targeted a minimum of 10 billion United State dollar to begin the execution of the NETP by COP27, start the local production and assembling of electric vehicle, and solar energy system decentralization in the country by 2025, and ensure knowledge transfer in partnership with research institution[12]. To encourage the generation of electricity using renewable energy technology, the federal government has introduced[13]

5 This is contained in the Forward pages of National Climate Change Policy for Nigeria 2021-2030.
6 The Act is known as the Climate Change Act 2021. It is the national plan on climate change.
7 The policy mechanism is outlined on the Page 19 of the National Climate Change Policy for Nigeria 2021-2030 as published by the Federal Ministry of Environment, Department of Climate Change.
8 www.energytransition.gov.ng accessed on 11th July, 2023.
9 This is the highest decision-making body in the Nigeria federation.
10 https://energytransition.gov.ng/implementation/ accessed on the 11th of July, 2023.
11 ibid
12 ibid
13 ibid

> Feed-in tariffs to regulate the price of electricity generated from renewable sources as a means of ensuring adequate return on investment; tax holiday of 5 years for pioneering company in independent power generation…

However, available information on the website[14] of the NERC reveals that electricity is generated in Nigeria from gas and hydro. Also, the power generation company are classified into gas and hydro respectively, and are owned by private and government. The information is presented in Table 1. below.

Table 1. List of Power Generation Company and Energy Sources in Nigeria

S/N	Name of Power Generation company	Source of power generation	Privatization Status	Power Generation Capacity
1	Afam Power Pls	Gas	Privatized	776MW
2	Sapele Power Plc	Gas	51 per cent sold	414MW
3	Egbin Power Plc	Gas	Privatized	1,020MW
4	Ughelli Power Plc	Gas	Privatized	900MW
5	Kainji Power Plant	Hydro	Concession	760MW
6	Jebba Power Plant	Hydro	Concession	578MW
7	Shiroro Power Plc	Hydro	Concession	600MW
8	Alaoji NIPP	Gas	Privatized	1,074MW
9	Benin	Gas	Privatized	451MW
10	Calabar	Gas	Privatized	563MW
11	Egbema	Gas	Privatized	338MW
12	Gbarain	Gas	Privatized	225MW
13	Geregu	Gas	Privatized	434MW
14	Olorunsogo	Gas	Privatized	NA
15	Omotosho	Gas	Privatized	451MW
16	Omoku	Gas	Privatized	225MW
17	Sapele	Gas	Privatized	NA

NA=Not Available

Source: Author Compilation (2023).

Discussion

It is evident from above that while there are existing plans by the government of Nigeria to support the use of renewable energy through the deployment of renewable energy technology as manifesting in the extant policies of government, that is National Climate Change Policy on energy for Nigeria 2021-2030, existing power generating plants in the country have neither adopted nor deployed renewable energy technology despite the Russia-Ukraine crisis effect on fossil fuel availability. This reality provides more insight into the Albert (2022) 'non-substitutability hypothesis' that the outright replacement of fossil fuel with renewable energy will require a systemic transformation. Also, Isah et al (2023) explanation that uncertainty in finance and government policies may have prevent the transformation to renewable energy provides understanding into the reason why the country maintains non-renewable energy sources. The

[14] https://nerc.gov.ng/index.php/home/nesi/403-generation

submission of Breetz et al (2018) that politics is the hidden determinant of transition to renewable sources of energy justifies the position of extant studies on the adoption of renewable energy technology.

Thus, it is evident that the electricity energy generation from fossil fuel and hydro is sustained and the implication of this is that while the price of fossil fuel continued to soar in the international energy market as evidence in the Russia-Ukraine crisis, energy continue to be sourced from non-renewable sources by household. Hence, fuelwood, fossil-fueled energy generating set, and charcoal are sourced by household to meet up routine energy need (Agbo et al., 2021; Ren et al., 2022). Hence, it remains evidence that the continuous reliance on fossil fuel to generate electricity has not allow for climate change mitigation in the country. This is because, the irregular power supply has only sustained further encouraged deforestation through the use of fuelwood (Inegbdion et al., 2020; Chudy-Laskowska, & Pisula, 2022). This, of course is with effect on climate change mitigation.

Conclusion

The study has analyzed how the effect of Russia-Ukraine crisis on fossil fuel accessibility is enhancing renewable energy deployment in electricity generation in Nigeria and noted that the extant fossil fuel and hydro power generating sources are still maintained in the country (Agbo et al., 2021). The reason for this is attributable to politics and the structural changes requirement (Breetz et al., 2018; Albert, 2022). As such, the Russia-Ukraine crisis and the soaring fossil fuel price has little or no effect on the transition to renewable energy policy in the country. Thus, politics rather than emergency situation drive energy transition.

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Joint Management Committee in Renewable Energy Projects as a Tool for Efficient Risk Management and Coordination

Mostapha Maddahinasab

Abstract: The Renewable Energy (RE)sector has been developed in some degree by government policies, but tools must be applied on a private-commercial scale for this sector to grow even more. These tools can be applied through the contractual relationships between the participants in a RE project. Many contracts are involved in a RE project that are not integrated in such a way that cooperation for improving risk management is possible. To reach that goal some contractual institutions are needed. One of them is the joint management committee (JMC). JMC has been used in the context of oil and gas contracts for a long time. And it has been one of the reasons that petroleum projects despite having high risks and long terms, thrive. In this research, the application of a similar structure for renewable energy has been studied and a format for that has been proposed. Hence, it has concluded that this structure can bring authorities, RE producers, and utilities together, and provide integrity to the contracts involved with a RE project.

Key words: renewable energy; joint management committee; contractual fiscal regime; feed-in tariff; electricity markets

Introduction

Electricity networks have special characteristics that constrain the market design and complicate analysis. Electricity demand and supply must be kept in balance minute by minute to maintain frequency and voltage. These requirements are normally met by giving a system operator direct control over the dispatch of power generation(Newbery 1998: 728). Thus, a dynamic collaboration framework between the parties and authorities in the electricity sector has always been challenging. The majority of legal systems still rely on regulation-based solutions that are not very collaborative and effective as the authorities are not in touch with the characteristics and the risks in each specific electricity project. Moreover, the current nature of the contracting framework in electricity is not capable of providing a framework that makes an efficient collaboration between all of the parties and authorities. In the renewable energy (RE) industry the situation is even more complex. There are different contracts relating to the different phases of the whole work ranging from constructing the power plants and grids to the distribution of electricity and feed-in tariff contracts. And there is not an integrated contracting format that includes all phases in a way that all involved companies work in a harmonious framework. The use of a separate contracting format for electricity projects will result in more costs that will ultimately be passed on to consumers, resulting in a lower consumer surplus. In addition, these separate contracts are usually simple service contracts that cannot bear complex contractual concepts that make a project more flexible and more manageable. The general hypothesis is based on the assumption of an integrated contracting format in electricity projects. Assuming such a contractual framework, I am going to examine the function of the Joint Management Committee (JMC) in actualizing the public energy policies in the most efficient and flexible way possible.

Current literature has articulated the concept of coordination through supply chains in the electricity sector. Additionally, scholars have proposed the design of suitable contracts and fiscal regimes to optimize the balance of the supply chain(Hult et al. 2002), (Wisner and Tan 2000), (Oliveira et al. 2013), (Cachon 2003). At the same time, however, there has not been enough research on the hardware and framework that can materialize such cooperation, fiscal regimes, and equilibrium.

This research aims at addressing this gap by analyzing the features, risks, and characteristics of the different contracts that currently shape a RE supply chain (RE project) Given problems that the currently used contracts encounter, this paper suggests an alternative r design for RE project, JMC that is used customarily in oil projects.

The methodology is based on applying the experiences of petroleum contracts in the RE industry. Hence, it is both, descriptive and analytical. First, with a qualitative approach, the paper provides an overview of current renewable energy contracts pointing out to the lack of coherency in the chain of contracts that results in poor risk management in RE projects. Second, the paper introduces JMC, as tool to be incorporated into the chain of RE contracts for solving the problem.

Types of electricity contracts

Electricity construction contracts

Power construction contracts govern the construction of power plants or power grids. Two contract prototypes are typically used in these projects; Private-Public Participation (PPP) contracts and turnkey contracts.

While turnkey contracts are pure service contracts, PPP contracts can range from concessions to Joint Ventures (JVs) to service contracts. Since public participation helps mitigate risks, PPP contracts are more applicable to projects characterized by higher uncertainty. Turnkey contracts on the other hand are suitable for projects where risks is lower.

Different variations to each of the two prototypes of the mentioned construction contracts exist. The most famous PPP contract is the Build-Operate and Transfer (BOT) contract. Under a BOT contract the contractor (private sector) builds and operates an infrastructure project for a defined concession period and then transfers it to public authorities. To motivate private sector investment into expensive and risky infrastructure projects such as the construction of power plants and power grids, governments must grant rents to the concession holders during their activities. (Auriol and Picard 2013: 187-188). BOT contracts grant temporary control and cash flow rights to the private concession holders to recover their investment costs and also gain the expected profit from the project based on an open or limited Rate of Return (ROR). By granting a longer concession period or higher ROR, or guaranteeing a certain level of ROR, the host governments can induce the private sector to invest more capital and bring higher technology. On the other hand, by methods such as taxation or sharing in the project's revenues, the host governments can control the concession holders' profits and prevent pitfalls for them.

Turnkey contracts are project delivery systems presenting a set of almost fixed obligations based on symmetric information. Therefore, the contractor can come up with an assessment of the CAPEX and non-CAPEX needed to be spent on the project. The prototype format of turnkey contracts is Engineering, Procurement, and Construction (EPC) (Chen et al. 2010: 599). Under an EPC contract, the main risks that the contractor bears are the economic risk of price escalation and the risk of delay in finishing the project. In return, the contractor receives a fixed remuneration fee plus cost recovery. Thus, the contract's fiscal regime is not complicated. Nevertheless, some factors can be added to EPC contracts developing into new formats that present more elaborate systems for more complex projects. For example, EPCF refers to a format in which the contractor takes care of the Financing (F) of the project too. Alternatively, sometimes, the contractor is obligated to operate and maintain the project as well (EPCOM). Hence, the fiscal regime of the contract is needed to reimburse the contractor for these duties too. When the expenses become heavier, to recover the costs and profits, a more flexible contractual fiscal regime is needed. To bring about such a fiscal regime that does not put more pressure and risks on the owner's shoulders, the contractor is usually entitled to recover the costs and profits from the project's revenues. To manage the risks of the project, as it gets bigger, contractors usually assign subcontractors to different phases or parts of the project. Therefore, a holistic approach is necessary for the efficient management of the project.

Electricity supply and sale contracts

The types of electricity supply and sale contracts vary based on various factors, such as the term of the contract, the quantity of electricity purchased, the market pricing system, and options for risk control under the fiscal regime. In a generic sortation based on the electricity market, there are three main types of electricity sale contracts:

- Wholesale contracts (also known as bilateral contracts or power purchase agreements),
- Spot contracts,
- Hedging contracts (future contracts, forward contracts, options and swap contracts),
- Feed-in Tariff contract (FIT).

Wholesale contracts

Contracts in the wholesale market are bilateral power purchase agreements between the power generators on one side as the seller and the utilities on the other side as the buyer. In such an agreement, the output of a power plant (entirely or partially) is sold for the long term (one year or more) to a utility for a fixed price. Power purchase agreements (PPAs) are large, long-term, and relatively infrequent transactions with large sums and considerable risks. (Huneke et al. 2018: 2) There is risk over prices of both inputs and outputs. A limited number of potential traders and low liquidity are common problems. PPAs are not suited to reacting to changing information about costs, demand, and prices. Therefore, managing the risks in these agreements is indispensable. In one respect, PPAs are critical adjuncts to generator financing (which provides returns on construction contracts), while in another respect, they provide utilities with their primary source of supply. To manage the producers' financial risks and utilities' demand risks, spot markets have been made where electricity is sold based on real-time prices for urgent demands. Based on different fiscal regimes, PPAs are categorized into five types:

- fixed charge payment,
- variable charge payment,
- incentive payment,
- transfer price.

Nevertheless, a fixed rate of return (fixed charge payment) is more common in the electricity sector (Jenkins and Lim 1999: 698). However considering the specificity of power from renewable sources, other fiscal regimes that reward taking more risk could be more appropriate.

Spot contracts

Generator face problems in the operation of the power plant at a more or less frequent basis. In the case of renewable energy, weather conditions make it impossible for the generator to supply the utility with the scheduled quantity of power under the PPA. In such cases, the energy supplier must buy the rest of the scheduled quantity from the spot market. Sometimes, demand for energy increases, and utilities themselves have to buy from the spot market in order to make up the deficit. In any case, the spot market works as a balancing market, which responds to real-time events that affect supply and demand.

Hedging contract

Since the volatility in spot markets is high, hedging contracts are used to control the risks of the volatile prices. (Deng and Oren 2006: 941)Uncertainty in demand is a common feature of commodity markets, which is mostly managed through using stored goods. As storage is challenging in the electricity market, the price in the electricity market is very volatile (Boroumand et al. 2015: 503). Therefore, hedging contracts are applied to manage the risk.

According to Zhang and Wang, ‘hedging is buying a derivative to offset the risk of a cash position, which is the amount of energy owned’. Hedging contracts are financial instruments (derivatives) that do not represent ownership rights in energy but rather derive their value from the value of an underlying commodity or another asset (Zhang and Wang 2009: 1547).

In terms of how they optimize risk management for utilities, there are different types of hedge contracts. The purpose of using hedging contracts is to distribute the volatile price risk in the spot market between the participants of the market (Liu et al. 2006: 2).
The hedging contracts can be categorised under four main types:

- Forward contracts,
- Future contracts,
- Options,
- Swaps(Deng and Oren 2006: 942).

A forward contract is a contract that obligates the holders to buy or sell an asset for a predetermined delivery price at a predetermined future time. Under a forward contract, the sum of the contract is paid at the maturity (delivery date) of the contract. Future contracts are similar to forwarding contracts as they also obligate the two sides of the contract to sell or buy electricity at certain rates in the future. However, there are differences between forward and futures contracts. A future contract is under regulations from the mandated authorities while forward contracts have no exchange regulations. Being based on exchange regulations a future contract has more liquidity.

Option contracts refer to agreements that gives the buyer of electricity the right to buy (call option) or to sell (put option) the electricity at a predetermined price (the strike price) over a specified period.

A swap contract is a contractual frame for exchanging a series of cash flows generated by underlying assets between two participants in the electricity market. Swaps are created in part to give price certainty at a cost that is lower than the cost of options. Under a swap contract, no commodity is actually transferred between the parties to the contract. Like forward contracts, swaps are also a form of on the counter (OTC) derivative, thus they are not in a centralized, standardized trading structure. In Nordic region and Britain, Swap contracts are known as contracts for differences (CFDs).

Feed-in tariff contracts

The electricity market by itself is complicated and risky due to the inherent features of the commodity that make it difficult to store it while its transmission is also limited by physical and reliability constraints (Liu and Wu 2007: 690).Renewable generation makes it even more complicated and risky, as it is more expensive (considering the low return on investment) than generation of electricity from burning fossil fuels. Thus, the support from government is inevitable for the promotion of renewable energies, at least in the initial phase of development of these clean energy sources(García-Alvarez and Mariz-Pérez 2012: 52).

Feed-in tariff (FIT), in general, is a public policy to promote renewable electricity production. Perhaps it is the most effective and popular public policy instrument that policymakers in different countries have come up with. According to the renewables 2019 Global Status Report (REN21 2019), more than one hundred countries in 2018 applied the FIT mechanism to develop renewable energies (Barbosa et al. 2020: 331).

Under the FIT mechanism, the renewable energy producers are entitled to sell all their production in the electricity network(García-Alvarez and Mariz-Pérez 2012: 53). FIT contracts are held between governments (or public/governmental utility companies) and the renewable energy producers guaranteeing the purchase of the produced electricity. In general, two FIT schemes are common in different countries:

- Fixed-price FIT (FFIT), which sets a fixed price for every unit of produced electricity,
- Premium based FIT (PFIT), which pays a premium on top of the market price.

FFIT transfers price risk from producers to consumers helping the renewable energy sector to have high and stable growth. Nonetheless, PFIT is better for matching the production with the marginal costs of the production and the costs of balancing intermittent electricity production may be lower with PFIT(Schmidt et al. 2013: 269-270). Therefore, the PFIT scheme is more suitable for big renewable energy projects. Furthermore, since the PFIT scheme is tied to the market price, enhances the counter effects between the different participants, and thus intensifying the necessity of constant coordination among them(Barbosa et al. 2020: 332).

JMC in oil industry

The petroleum industry is an extremely diverse and multifaceted sector. Many of the legal doctrines in international commerce law have been developed in response to the arrangements by which oil and gas have been extracted and sold (Martin 2004: 281).

Since the lease issued in 1857 to Colonel Drake in Titusville, Pennsylvania until now this industry has come a long way building the norms, institutions, and market structures of an internationally soft-regulated business(Talus et al. 2012: 186). Thus, nowadays, the term '*Lex Petrolea*' is a famous and meaningful concept in this industry that refers to the norms and mechanisms mostly accepted by the international and national companies in this sector (Maddahinasab et al. 2019: 50).

One of the mechanisms that has been developed within petroleum contracts is the joint management committee (JMC). In the early days of oil industry, only concessions were used; referred to as traditional concessions. The traditional concessions generally favoured the International Oil Companies (IOCs) as they included few obligations for the latter. IOCs had to only pay a royalty to the host states. The rest of the project, production, work program, and the technology in use was up to the IOCs themselves (Talus et al. 2012: 186). Thus, as host states had no role in the projects, no JMC mechanism was considered in the traditional concessions unless there was a joint venture (JV) between some IOCs. In that case, there would be an operating committee between them that had a similar function as JMC[15].

In the post-World War II era, nationalism movements led to the rejection of traditional concessions, seen as unfavorable for host states. They were gradually replaced by modern concessions that include more obligations for IOCs and more supervision and inspection rights for the host countries. To be able to exert even more control over IOCs, some countries have applied risk-service contracts in which IOCs act as contractors working on behalf of the National Oil Companies (NOCs)[16]. Additionally, some other host states opted for Production Sharing Contracts (PSAs), a contract that has characteristics of both risk service contracts and modern concessions (Talus et al. 2012: 186-188). Moreover, as other industries relied on carbon energy, the petroleum industry had to develop increasingly. That required more investments and taking more risks, which led to using more JVs and Joint Operation Agreements (JOAs) in most of the upstream projects(Roberts 2010: 16). Ongoing developments in the oil sector and updates on the contracts required an integrated strategy for better management of the projects. To meet this need, thus, JMC was developed.

<u>JMC's function in oil contracts</u>

Petroleum contracts usually set out that the parties to the contract must form a JMC after a specific period of time from the date of the contract being in force. This period of time may vary in each contract ranging from 30 days to 90 days since the contract's effective date. As an example, the PSA model in Cambodia stipulates that within 60 days of the effective date, a JMC shall be established. Under the Iraq model of oil risk-service contracts, JMC is to be established only 30 days after the effective date. This committee usually consists of an equal number of members from both parties to the contract. For example, in the Iraq's service contract model, the owner (Iraqi NOC) nominates four members including the chairman of the committee. And the contractor also nominates four members for the JMC. In service contracts and PSAs, however, the host states or NOCs have more power than contractors' representatives because they are the owners of the project and its production. Thus, the JMC's decisions in these contracts are required to be approved by the representative of the host state. On the contrary, in modern concessions, IOCs have the upper hand in JMC, as they own the project and the produced oil. Therefore, in the JMCs within concessions, although host states participate in making decisions as far as they are related to their benefits, they are not in the commanding position.

[15] JMC term is mostly applied when the host state is also involved.
[16] IOCs (International Oil Companies) are privately or publicly traded companies that operate globally, focusing on exploration, production, and sale of oil and gas resources. NOCs (National Oil Companies) are state-owned entities that control a country's oil and gas reserves, responsible for managing exploration, production, and often marketing within their jurisdiction, prioritizing national interests.

JMC makes all major decisions regarding the management of the petroleum operations including approval of all major expenditures, evaluation of the results of the exploration, planning and drilling of wells, and determination of the commerciality of the drilling results(Jennings et al. 2000: 613). Generally, the functions and duties of JMCs include planning the work programs and budget, reviewing progress of the operator's work, supervising terms of contracts to be executed, resolving problems arising in petroleum operations, supervising and inspecting the operations. As to different aspects of petroleum projects, a JMC may have different subcommittees concerning technical, financial, economic, social and environmental issues (Johnston 1994: 170). Typically, a JMC in a petroleum project has a technical subcommittee for dealing with technical issues, a budget subcommittee to analyse the proposed annual work program and budget. Audit subcommittee to inspect and supervise operator expenditures in accordance with the approved annual work program and budget. Subcommittee for marketing and financial matters.

JMC design for an integrated RE contract frame

JMC applies well when there is a big RE project that requires heavy risk-taking investment, in which case the government is participating in the project. For example, there is a BOT contract between a RE producer and the government (or a utility) to construct and operate an offshore wind plant or extensive solar plants. The government provides the producer with a PFIT, and there are predetermined utilities that purchase electricity from the RE project. In such RE system it is vital to keep the project profitable while competing with cheaper electricity. That means, although the price for the electricity produced from RE must be more than marginal costs, it also needs to be low enough to be able to compete with other sources of energy. To reach this goal, a solid, integrated collaboration is needed between certain participants in the RE project. RE JMCs are tasked with providing this collaboration framework.

It should be noted that each RE project must have its own JMC that only deals with that specific project with its unique risk profile.

<u>The participants in JMCs</u>

The main participants of a JMC are representatives of the government, the RE producer company (operator) and the utilities that in any case can be experts in different relevant fields. Also, in some cases there could be representatives from the grid owners and companies that facilitate power transmission.

<u>The government representatives</u>

In the JMC for a RE project, the government's representatives mainly are to secure the public policies and government's contractual obligations and rights being held properly in accordance with the efficient management of the project. Between the government and operator (RE producer) can be two contractual relationships. The first is the construction of a RE plant. Then there will either be a BOT or an EPCM between the host government and the producer. Also, a PFIT which regulates the producer's rate of return (ROR). Thus, the PFIT has a direct effect on the BOT/EPCM fiscal regime. On the other hand, between the government and utilities that buy energy from the RE project, there are regulatory relations such as requiring the utilities to buy electricity from the RE plant at a price based on a certain formula that keeps the price above marginal production costs and also low enough to compete with regular electricity and supporting the consumers' benefits. In this context, one could add green certificates or renewable portfolio standards (RPS) between the government and utilities that need to be adjusted between them in the JMC. RPS is also a famous public RE policy that has been applied in the USA energy system. Based on this mechanism, utilities are obliged to provide a certain portion of their capacity through purchasing power from RE producers(Kreycik et al. 2011: 1-2).

Additionally, the government's representatives may be concerned about the oversight of activities subject to RE regulations, such as competition regulations. In addition, other regulations and contractual terms and clauses such as the other parties' obligations needed to be supervised to avoid disputes and deadlocks.

<u>Producer and utilities</u>

The main relationship between the utility and the producer is the power purchase agreement (PPA), which establishes a long-term plan for purchasing power based on a price formula to reduce market risks. Hedging contracts can be embedded in the PPA with the format of hedging clauses. For example, options to buy or sell electricity (call / put options) at a certain price can be embedded in a PPA as well. Thus, the holder of an option is able to exercise it depending on the market situation and the fluctuations in the spot market price. Hence, a lot of future disputes and bottlenecks resulting from volatile electricity prices will be avoided (Kamat and Oren 2002: 837).

A JMC in this context can be very helpful as it provides a regular setting to adjust the PPA's fiscal regime and its hedging strategies.

<u>Functions of the JMC</u>

Power production output in RE sector is highly variable compared to fossil fuel generation. Uncertainty and limited accuracy in RE production, limitations on the transmission system, increased need for backup and impact of unpredicted large ramps, conflicting benefits of the participants in the RE market and coordination with the regulatory agencies are amongst the most demanding issues of RE projects. It is necessary for RE projects to have a ready and regular structure for coordination between the participants to bring about the most efficient decision regarding freshly updates in the RE market so that the mentioned risk can be properly managed(Bitar et al. 2010: 1920). The assumed JMC must be capable of achieving this goal.

Also, the JMCs in RE projects must provide an efficient procedure for the governments to supervise over the RE project and the relevant markets. Usually, one of the most annoying and discouraging elements in RE sector is the frequent regulatory decisions that affect the projects and markets. However, governments, by applying such policies are trying to promote RE sector, nevertheless, as the decisions are applied on a general level, it creates regulatory risks for both the producers and the utilities. Moreover, bureaucracy will slow down the sector. One of the most important functions of RE project's JMC is to provide a dynamic setting for the public/governmental representatives to supervise the projects and provide them with the support that they need.

Another function that the designated JMC must provide is to set up each RE project with annual work and budget plans so they aligned with the long-term goals of the governments in the energy mix. Each year, \decisions need to made on how the capital for the expenditures needed for the goals is going to be supplied to achieve these goals set. These capitals may be provided by different methods such as financing, income from the project through the selling of the produced electricity and subsidies from the government. The JMC also must provide an auditing setting to make sure that the cash flow of the project is in the optimized balance and providing the procedure with a transparency needed for such projects, as, due to the existence of governmental supports in RE projects, they can be susceptible to corruption (Lapatinas et al. 2019: 104).

Moreover, the JMC in a RE project is to provide a structure in which the contractual fiscal regimes in the different contracts involved in the project (construction, PFIT and PPA) are adjusted according to the facts and risks in the project and also according to the regulatory fiscal regime such as taxes and tariffs in any case that is relevant.

Another function of the JMC is to provide the RE projects with a regular and dynamic technical and technological assessment in order to apply the newest technologies in the project so that it can stabilize against the risks.

Format of the JMC

As a JMC in a RE project involves more participants from different sides, the format of the JMC is a key element in achieving the goals. Therefore, it must include different subcommittees that deal with different issues based on timely plans. there can be subcommittees in demanding issues of a RE project such as adjusting the fiscal regimes, technical issues such as transmission and energy storage etc.

The main JMC session can be held yearly or quarterly depending on the characteristics of each RE project. Exceptional sessions can be held in urgent cases following predetermined procedures.

Like the functions of JMC, its procedures must be stipulated in the contracts that bind the participants in a RE project.

Conclusion

Current RE development strategies that are dependent on public policies have reached their limit. In most of the legal systems, governments have established macro-level policies that have grown RE to some extent. For reaching the goals for decarbonisation and clean energy, it will be crucial that the micro-level institutions in the markets and RE/electricity contracts evolve so that RE can develop on those grounds too. This article proposes a contractual tool that is common in the petroleum contracts, known as a joint management committee (JMC). JMC facilitates cooperation and harmony within a complex project. As cooperation and harmony between different participants of a project is a crucial element in development of RE projects, a proper JMC format can be a helpful contractual tool that sets RE development forward on its specifically micro-levels.

This research has concluded that a JMC structure in a big RE investment project can facilitate government's supervision in a way that does not impede the development of the project and also the government's supervision will be more effective as their representatives are present in the project constantly and regularly according to the agreed procedures of the JMC. The JMC can also optimize the risk-sharing among the participants in the supply chain of the contracts in a RE project.

As different contracts are involved in a RE project from construction to selling in the market, the JMC can provide a structure in which these contracts can become integrated and work in response to each other. The changes in one contract (for example, the fiscal terms) would not create risks in another.

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British transformation towards a low-carbon economy in the light of intergovernmental relations reform

Arkadiusz Cygan

Abstract: Implementation of the UK's ambitious greenhouse gas emissions reduction targets is entering a new phase. The focus is shifting from the energy sector towards areas where devolved administrations in Scotland, Wales and Northern Ireland have many more competences gained through devolution reform. The aim of this article is to present the perspectives of British decarbonization in the context of the evolution of the model of intergovernmental relations. This article seeks to assess the extent to which the achievement of the decarbonization goals will depend on devolved administrations and determine whether the IGR reform carried out in January 2022 strengthens the foundations of the British transformation towards a low-carbon economy.

Key words: UK, devolution, intergovernmental relations, climate policy, climate change

Introduction

Following the June 2019 amendment to the Climate Change Act (CCA or the Act), the UK became the first major economy to commit at the national level to achieving climate neutrality (net zero) in 2050. In subsequent years, the UK also set intermediate emission reduction targets, i.e. 68% by 2030 and 78% by 2035[17].

Much of the scientific literature was thus naturally devoted to the goals the Act defined and the tasks of institutions it created. The impact of the devolution reform carried out in 1998, i.e. the specifically British decentralization process (Kaczorowska 2015: 34), as well as the resulting inter-institutional relations on the prospects of achieving the aforementioned decarbonization goals, has so far enjoyed less interest from researchers. However, this topic deserves more attention because both the net zero goal and the intermediate emission reduction targets are defined as nationwide, without specifying the responsibilities or compelling individual constituent parts of the UK to deliver any specific share of these commitments.

The significance of the topic also lies in the fact that, following the conclusion of negotiations on the legal architecture of the global climate regime, the emphasis is now shifting from defining the level of climate ambition towards the implementation of the set goals. Given the global nature of climate change, the topic raised in this article is important not only to the UK specifically but also to wider decarbonization efforts around the globe. For years, the UK has been positioning itself as a leader in the area of climate policy. As one of the richest and most developed countries in the world, which in addition is historically responsible for a large share of cumulative greenhouse gas (GHG) emissions, any failures in achieving British emission reduction targets not only may have repercussions for the UK domestically but also would send a negative political signal internationally that could become an excuse and argument for countries advocating for lower climate ambitions.

[17] 68% target as part of the British Nationally Determined Contribution (NDC) to the Paris Agreement; 78% target results from the sixth carbon budget adopted on the basis of the CCA.

The aim of the article is to present the prospects for the implementation of the British transformation towards a low-carbon economy in the context of the evolution of intergovernmental relations (IGR). The research problem boils down to the extent to which the achievement of the UK's decarbonization goals will depend on the devolved administrations in Scotland, Wales and Northern Ireland. Additionally, an answer was sought to the question of how much the IGR model reform strengthens the foundations of the British transformation. The multi-level governance (MLG) concept was used in the analysis. It is supported, alongside academic literature, by a wide range of sources, including government publications, legal acts and evidence from parliamentary committee reports, which shed light on the practical aspects of the subject under discussion.

The article consists of an introduction and five parts. The first part presents the MLG concept and provides the justification for its use in this article. The most important features of the constitutional changes introduced through devolution reform are also highlighted. The second part discusses the formal position of the devolved administrations in the British decarbonization process in accordance with the CCA, as well as their importance for further climate action. The article's third part outlines the evolution of IGR and presents their new structure, while the fourth part considers how the new model deals with selected problems that have characterized British IGR so far. In the fifth part (Summary), an attempt is made to answer the research problems.

Multi-level governance and devolution reform in the UK

The first use of the term MLG is attributed to Gary Marks. In his definition, MLG is "a system of continuous negotiation among nested governments at several territorial tiers – supranational, national, regional and local – as a result of a broad process of institutional creation and decisional reallocation that has pulled some previously centralized functions of the state up to the supranational level and some down to the local/regional level" (Marks, 1993: 392).

As Ansell and Torfing point out, governance is "one of the most fashionable and frequently used social science terms in the world. Part of the attraction is that the notion of governance signals a weakening of the state-centric view of power and social steering" (Ansell, Torfing, 2022: 2). The term governance therefore suggests decentralization of the decision-making process, including the growing importance of non-state actors in this context. This is related to the "multi-level" term, which indicates that governance takes place at different levels, both at the national level, and below it (subnational level) and above it (supranational level).

Although the MLG concept was created in the context of European integration studies, in the following years it has been developed and used to describe the phenomenon of the spread of political power from the central level in other policy areas. The use of MLG in this article allows one to place the CCA in a broader context than would be suggested by the nationwide nature of the UK's decarbonization objectives. Thus, this was the basis for the description of the relationship between the UK Government (central level) and subnational governments within the UK (the vertical aspect of MLG) and the analysis of the impact of the new IGR governance architecture on the prospects for achieving decarbonization goals.

The application of the MLG concept in the context of British political studies became even more justified after the devolution reform. The emerging institutions and the new political dynamics forced supplementation of the Westminster model (WM), which was once dominant in describing British politics. Cairney points out that, "while the WM suggests a centralized, unitary state in which there are clear lines of accountability and hierarchical control, MLG suggests a disaggregated, quasi-federal state in which control is replaced by influence within a political system with multiple lines of accountability and uncertainty about where the 'top' (or centre) is in different situations" (Cairney, 2012: 161).

Under the Scotland Act 1998, the Northern Ireland Act 1998 and the Government of Wales Act 1998, the legislative and executive bodies, i.e. parliaments and governments/executives, have been created in these parts of the UK (in general, devolution did not extend to England, the largest and most populous part of the UK). Bogdanor describes devolution as "transfer to a subordinate elected body, on a geographical basis, of functions at present exercised by ministers and Parliament. (…) – within a primary legal framework still determined at Westminster" (Bogdanor, 1999: 2-3). The delegation of some legislative and executive powers (to a different extent) to the authorities in Scotland, Wales and Northern Ireland means that in principle the UK Government does not have full competence and freedom of action in all policy areas. In some cases, it is reliant on subnational authorities, which in theory may accelerate the transformation towards a low-carbon economy within the scope of their own competences, or on the contrary, carry out obstructive activities.

It should be noted, however, that "the essence of devolution is that power is devolved in the process, not transferred, as the sovereign UK Parliament does not ultimately relinquish its power. (…) The Parliament in Westminster can repeal any law, including devolution laws, which are the most important parts of the British constitutional system, by the ordinary legislative procedure" (Rajca, 2017: 156). Scotland, Wales and Northern Ireland cannot therefore be treated as independent. UK Parliament – in line with the principle of parliamentary sovereignty – still has the power to decide on all matters, including those devolved[18]. In theory, it could even re-centralize power. However, such action seems highly unlikely from a political point of view (Bogdanor, 1999: 287).

This issue becomes all the more important as the UK's transition to a low-carbon economy is now entering its next phase. The focus of decarbonization efforts is now shifting from the energy sector to other parts of the economy, where devolved administrations have many more competences and where policy actions will directly affect citizens to a greater extent than before.

Devolved administrations in the British decarbonization process

The CCA creates the institutional and functional framework for the British transformation towards a low-carbon economy. The provisions of the Act's first part (Carbon target and budgeting) introduce some GHG emission reduction targets (and the rules for setting intermediate targets in the future). These targets are national, i.e. they concern the country as a whole, without specifying individual contributions from the UK's constituent parts. The existence of devolved administrations is taken into account in the Act, although in this part of the CCA, it primarily comprises the consultation duties of the Secretary of State before making a given decision.

[18] Under the Sewel Convention, UK Parliament will not normally legislate on a devolved matter unless it receives a legislative consent motion from a devolved legislature. The Sewel Convention is not considered legally binding and has already been broken on two occasions.

It is on the Secretary of State (SoS) – the authority at the central level of government – that the CCA imposes specific obligations in the context of decarbonization. The SoS is formally responsible for achieving the emission reduction targets, setting carbon budgets or presenting measures aimed at their implementation. Although the nature of these obligations has been the subject of debate in the literature[19], there is no doubt that any failures will have significant consequences, if only political.

Such attribution of responsibility for achieving decarbonization targets emphasizes their nationwide character. It can also be read as an expression of the desire to maintain the leading role of the central level of power in British transformation towards a low-carbon economy. However, while the central level seemingly maintained control over the general direction and the pace of transformation, the devolution arguably left the SoS dependent in certain areas on devolved administrations in relation to the implementation process.

Although Section 14 (5) of the CCA implies an obligation to involve devolved authorities at the stage of developing strategic documents and designing implementation activities, it does not respond to the need for interaction between levels of government resulting from day-to-day policy implementation issues. It seems that the Act does not provide a sufficient answer to the implementation challenges resulting from the existence of the devolved administrations. This view is intensified by opinions of some authors, who, referring to the nature of the obligations imposed on the SoS in the CCA, indicate that the SoS has the "duty not just to do something but to ensure the achievement of a specified outcome which depends on the cumulative conduct of a wide range of parties" (Reid, 2012: 749).

A response to the indicated implementation challenges was then meant to be provided by the Climate Change Act 2008 Concordat, an agreement detailing some issues of intergovernmental cooperation in the area of the CCA. More than a decade later, the Interministerial Group (IMG) on Net Zero, Energy and Climate Change was also formed. The experience of Scotland, Wales and Northern Ireland, however, shows that intergovernmental contacts within these structures so far provide only limited engagement in some cases[20], the discussions are often superficial (Welsh Government, 2021: 1), and the scope and manner of conducting consultations was often ineffective and prevented devolved administrations from actively participating in the meetings (Scottish Government, 2021: 2).

An additional obstacle to effective cooperation was that individual IMGs often worked in silos, which meant that intergovernmental coordination – which minimizes cost and disruption – took place only when essential, and policies were most often created in isolation from the work in other formats. Julie James, Welsh Minister for Climate Change, pointed out in August 2021, with reference to the IMG on Net Zero, Energy and Climate Change, that "there are, of course, similar IMGs covering other ministerial portfolios. Each of these should also be discussing the response to the climate emergency. Yet to my knowledge there is no cross-government system in place for joining up the activity of the various Groups" (Welsh Government,

[19] The prevailing opinion is that the SoS' responsibilities are mainly political, not legal, in nature, *vide* above all Feldman, 2016: 222.

[20] A good example of this was the announcement of Hydrogen Strategies by the UK and Scottish governments. Both documents set a production target of 5GW by 2030, suggesting little coordination in the process of developing these strategies. One year later the UK government increased its target to 10GW.

2021: 2). All of this prompted the Climate Change Committee (CCC), the advisory and oversight body created by the CCA – as per MLG, another actor weakening the UK Government's authority – to state in its 2022 Progress Report that "it remains unclear how central, devolved and local government will operate coherently towards the Net Zero goal" (Committee on Climate Change, 2022: 15).

For the purposes of this article, it also seems useful to take a closer look at the distribution of competences in the areas most important in terms of the transformation towards a low-carbon economy.

Table 1. Balance of devolved power by sector

Sectors where key policy levers are 'mostly' devolved	Sectors where key policy levers are 'partially' devolved	Sectors where policy levers are 'mostly' reserved
● Agriculture ● Land use, land-use change and forestry ● Waste ● Buildings (NI) ● F-gases	● Buildings (S, W) ● Surface transport ● Electricity supply (NI)	● Electricity supply ● Fuel supply ● Manufacturing & construction ● Aviation ● Shipping ● Bioenergy with carbon capture and storage (BECCS) for power generation

Source: Climate Change Committee, 2020: 233.

As already mentioned, the devolution is asymmetrical, i.e. in principle it does not cover England, and the scope of competences transferred to other constituent parts of the UK varies. It should be emphasized that the division presented in Table 1 is in fact a simplification. The division of competences between the UK Government and the devolved administrations is often blurred, and a given competence will not only be difficult to isolate precisely but also most likely overlap with other competences to some extent. An often-cited example of this is the issue of nuclear power in Scotland. Energy, albeit not in Northern Ireland, is a reserved matter. Despite this, the opposition of the Scottish Government to the development of nuclear energy on Scottish soil, combined with its competences in the field of spatial planning, meant that the Scottish Government has de facto a veto right in this matter, especially when it comes to the construction of new infrastructure (Heffron, Nuttall, 2017: 103-126).

To look at this matter from another perspective, the CCC stresses that devolved administrations can "ensure that UK policy in reserved areas (e.g. a regulatory phase-out of petrol and diesel cars sales) is delivered effectively through the provision of additional incentives, public engagement, and supporting policies such as planning" (Climate Change Committee, 2020: 206). The above examples indicate a high degree of interdependence of central and subnational authorities in the implementation of decarbonization policies, which makes effective independent actions by a given authority virtually impossible.

Scotland, Wales and Northern Ireland together accounted for almost 25% of all UK GHG emissions in 2018. It should be noted that the UK has achieved significant reductions in GHG emissions in recent years. Between 1990 and 2021, UK territorial GHG emissions fell by almost half, thanks largely to the energy sector, where emissions fell by 69% (Department for Business, Energy and Industrial Strategy, 2023: 7&18). Maintaining this pace and further decarbonization progress will thus largely depend on policies in areas that are much more devolved than energy, e.g. transport or agriculture.

Scotland, Wales and Northern Ireland are covered by the CCA and are therefore required to pursue the objectives set out therein. The Act, however, does not impose any specific obligations on them in this regard, e.g. an appropriate share of emission reductions in line with the overall UK-wide reduction trajectory. Devolved administrations adopted their own climate framework laws and independently defined their goals, inspired by the CCC recommendations. The practice shows that the approach of the UK's constituent parts to the implementation of decarbonization goals has so far been differentiated. While the climate legislation is well established in Scotland and Wales, Northern Ireland has for many years been taking a conservative stance. The Northern Irish Climate Change Act only entered into force in June 2022.

It seems that at present, both at the central and devolved level, there is a declared convergence with respect to decarbonization. This convergence, however, does not preclude conflict or political competition that may prove counterproductive (Gallagher, 2012: 209-210). One cannot also exclude future disagreements in this area, given changes in governments and socio-economic conditions, especially taking into account the need to take decarbonization action in more socially sensitive areas.

Due to the formal achievement of the foregoing GHG reduction targets, the British model of climate transformation established in the CCA has not yet been tested in political practice. In fact, the British transformation is largely affected by the policy gap problem (mismatch between actual activities and the assumed goals), which has been consistently pointed out by the CCC in recent years. UK Government's estimates indicate that the UK will meet its fourth carbon budget target by a small margin, but current policies will not be sufficient to deliver the fifth (covering the period 2028–2032) and sixth (2033–2037) carbon budgets (Department for Business, Energy and Industrial Strategy, 2022: 5).

Against this background, creating conditions for an effective cooperation between the central and subnational level of power becomes a challenge, largely determining the achievement of the declared GHG emission reduction targets. The current delivery infrastructure seems to be underdeveloped, and the numerous decarbonization strategies in various policy areas seem not to be matched by a robust delivery roadmap. The new IGR model introduced in January 2022 is in this context an important development.

British intergovernmental relations: the new IGR structure

The new IGR arrangements can be viewed as a response to the criticism of the previous model, based primarily on the Memorandum of Understanding defining the basic principles of interaction between governments, as well as on interministerial concordats. The Joint Ministerial Committee (JMC), representing all four governments and operating in various compositions, played a key role in the previous IGR model. A number of challenges, including Brexit and the COVID-19 pandemic, have exposed to a greater extent the weaknesses of the previous model, e.g. irregularity of JMC meetings, shortcomings in transparency or dispute resolution mechanisms. At the same time, these events demonstrated the benefits of maintaining strong IGR.

The new model was presented in January 2022 in The Review of Intergovernmental Relations (Review), which is the result of joint work of the UK Government and devolved administrations.

Table 2. New IGR structure

Tier of engagement	Composition		
I	Prime Minister and Heads of Devolved Administrations Council (The Council)		
II	Interministerial Standing Committee (IMSC)	Finance: Interministerial Standing Committee (F:ISC)	*Time-limited* Interministerial Committees (ICs)
III	Interministerial Groups (IMGs), e.g. on Net Zero		

Source: own study based on: Cabinet Office and Department for Levelling Up, Housing and Communities, 2022: 3-4.

IGR became much more structured. Contacts take place on three tiers. The lowest level consists of IMGs established on specific policy areas. These groups are expected to meet regularly on a quadrilateral basis, albeit the meetings are explicitly allowed to be organized in a different format, e.g. bilaterally[21]. Appendix B to the Review provides a tentative list of IGMs. It is worth noting that IMGs operate in areas in which competences are generally devolved, as well as in areas where the powers are reserved for the UK Government (e.g. IMG on trade). This is important given how devolved administration can influence policies in reserved areas, as outlined in the second part of this article.

The second tier is formed by the Interministerial Standing Committee (IMSC), the Finance: Interministerial Standing Committee (F:ISC) and the time-limited Interministerial Committees (ICs). The IMSC, made up of relevant IGR Ministers[22], is a forum for dealing with issues of a cross-cutting nature, beyond the remit of a single IGM. The IMSC will also deal with matters of wider political importance, also in the international dimension, affecting the state of relations between governments. It is also a forum for dealing with issues transferred from a lower level under the dispute resolution mechanism. Meetings in this format will be held on a rotating presidency basis every two months, subject to the possibility of organizing meetings more or less frequently, depending on the needs and reaching a consensus on this matter.

The Review also provides for the possibility of creating ICs, special committees with a limited functioning time, to consider a given problem, which, for example, due to urgency, should be considered by ministers separately.

Formally, at the second IGR tier there is also the F:ISC, which is formed by ministers responsible for finance. This is the main forum for discussing financial matters, which generally takes place quarterly, although as with the IMSC, ministers may meet more or less frequently as needed. The position of this forum seems to be distinguished, e.g. due to the establishment of a separate Secretariat to handle its work (F:ISC Secretariat) or the establishment of separate terms of reference.

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[21] Asymmetrical nature of devolution is especially conductive to bilateral IGR, which has so far eclipsed in importance multilateral engagement, *vide* Swenden, McEwen, 2014: 496-497.

[22] Ministers from other departments and ministries can also be invited.

The creation of second-tier bodies potentially presents the greatest added value in the context of the existing net zero governance structure, considering that the net zero goal and the intermediate goals are essentially cross-economy targets. Taking into account the inefficiency of the existing cooperation forums, as signalled in the previous part, it seems that the IMSC in particular can serve as a useful forum for engagement between the ministers in each government, providing a desirable whole-system perspective.

The highest tier is made up of the UK Prime Minister and the First Ministers of Scotland and Wales and the First Minister and Deputy First Minister of Northern Ireland, who together function as the Council. It is always chaired by the UK Prime Minister, and meetings are to be held at least once a year. The Council is responsible, among others, for providing political direction and general oversight of the IGR. It also serves as the last instance in the dispute resolution process.

The Council, IMSC and ICs will be supported by a permanent IGR Secretariat, composed of representatives from all governments. In addition to its organizational (e.g. preparing discussion materials) and transparency (e.g. preparing activity reports) duties, the Secretariat is also given an important role in the dispute resolution process, which will be discussed in more detail in the next section.

The new model in the context of the existing IGR issues and prospects for meeting GHG emission reduction targets

McEwen identifies five types of situations where intergovernmental cooperation is needed:

1) exchange and search for information, e.g. on current or planned policy initiatives;

2) negotiating intergovernmental agreements or coordinating joint ventures;

3) the exercise of influence by authorities at the subnational level on matters that directly or indirectly affect their jurisdiction;

4) maintaining or strengthening autonomy, e.g. in terms of negotiating the extension of competences or defending against interference of the central level in the transferred areas of competence;

5) avoiding or resolving disputes (McEwen, 2017: 669-671).

The importance of IGR was largely demonstrated by the COVID-19 pandemic[23]. As Andrews points out, "the coronavirus crisis has shone a stronger UK spotlight on the devolved governments than anything since the tuition fee debates of 2010, and for a far more prolonged period. While the UK entered its first lockdown on 23 March 2020 with considerable four-nations unity, and a four-nations approach had been announced on 3 March, the exit from that first lockdown saw marked divergences of approach emerge, with different strategies, visions and representations of leadership" (Andrews, 2021: 514). The way of managing the relationship between the UK Government and the devolved governments established in the previous IGR model turned out to be ineffective. The new IGR model is a partial response to the identified shortcomings, especially in terms of intensifying and systematizing intergovernmental contacts. However, IGR effectiveness is also affected by other factors identified in the literature, among which the most important seem to be the issue of decision-making, dispute resolution, the problem of England's representation and transparency.

[23] Health has been a primarily devolved matter since 1999.

In the previous model, the JMC was clearly defined as "consultative body rather than an executive body, and so will reach agreements rather than decisions" (The United Kingdom Government, the Scottish Ministers, the Welsh Minister, and the Northern Ireland Executive Committee, 2013: 13). The new IGR model largely replicates this principle. It is indicated that decisions may be made, but still "on the basis of agreement by consensus. The default position will remain that a joint approach will not be taken in the absence of such consensus" (Cabinet Office and the Department for Levelling Up, Housing and Communities, 2022: 2). Such design is not necessarily a problem for future decarbonization challenges, as IGR meetings can still serve as a forum for dialogue and information exchange in the absence of consensus. Nonetheless, the inability to reach a consensus may in some instances lead to a decrease in the participants' involvement in IGR work and a decrease in the real political significance of the meetings. This would especially be true if one of the governments decides to adopt a sceptical position towards climate change. Another threat may be the possibility of using the lack of consensus to disguise passivity and reluctance to take more progressive policy actions.

Policy divergence between British governments is not a priori undesirable. As Shaw, MacKinnon and Docherty indicate after Jeffery, devolution "grants the devolved administrations the capacity to develop policies that are better tailored to the economic and social conditions of their areas" (Shaw, MacKinnon, Docherty, 2009: 547). There is no doubt that many net zero policies will vary locally, taking account of specific local circumstances. This is facilitated by the fact that "the UK Government transfers tens of billions of pounds each year (…) without seeking any say whatsoever over how it is spent" (Gallagher, 2020: 574). In some cases, however, there still will be a need to agree on a common approach or develop nationwide initiatives. Conflicts in the previous IGR model could not be effectively resolved, primarily due to the possibility of vetoing by one of the parties to the dispute a decision to take a disagreement to the formal dispute resolution process. The new IGR model to a large extent refers to this problem. A completely new, three-stage dispute resolution mechanism has been designed, in which the Secretariat will play the main role. The Secretariat, and not the parties to the dispute, will be able to decide, on the basis of specified criteria, whether a given conflict should enter the formal dispute resolution process. It is also worth noting here that the formal role of the UK Government was diminished as it lost the right to preside over the entire process. Different rules, however, apply to disputes concerning financial matters, which can only be escalated in the case of "when there is reason to believe a principle of the Statement of Funding Policy may have been breached" (Cabinet Office and the Department for Levelling Up, Housing and Communities, 2022: 14), which underlines the dominant role of the UK Government in the financial area.

The lack of a separate England representation within the new IGR model is another issue[24]. As McEwen points out in the context of the British Government's efforts to combat the COVID-19 pandemic, "the UK Government are simultaneously speaking for the UK as a whole and also acting as the Government of England. That has been at the source of some of the confusion in the public health messages, where it was not always clear and it has not always been made clear when the messages are directed at England alone and where they are directed at the UK as

[24] The so-called West Lothian question. Issues concerning England are decided by the UK Parliament. MPs from Scotland, Wales and Northern Ireland are thus eligible to vote on issues that affect England, but it does not work the other way round.

whole" (Scottish Affairs Committee, 2020: 6-7). The same may also occur in relation to decarbonization and complicate some policy processes, e.g. creating coherent and clear communication strategies, which seem essential from the point of view of a wider problem of building public trust and support for climate action.

The issue of insufficient IGR transparency has also been highlighted in the scientific literature[25]. Information, if made public at all, was most often very perfunctory and did not provide insight into the course of the discussion or its dynamics. The new IGR model attempts to mitigate this problem, including by encouraging the publication of post-meeting communiqués with summaries of the topics covered. Experience after more than a year of the new guidelines being in force, however, does not indicate a fundamental change in this regard. Communiqués are published regularly, but their content still usually does not reveal the course of the discussion. This hinders not only political oversight by parliaments but also that exercised by non-governmental organizations. The lack of transparency around IGR discussions, especially when they concerns trade-offs between UK regions, presents a high potential for conflict. Considering that in the coming years, efforts to combat climate change in the UK will affect devolved policy areas to a larger extent than before, the current low level of transparency may become a political challenge, making it difficult to build trust and public support for climate action.

Summary

Climate scepticism is still present in the British public debate[26], but even despite the political turmoil of recent years[27], the discussion on slowing British transformation towards a low-carbon economy or adjusting decarbonization targets has not seriously become part of the political agenda of any major UK political party. The transformation is likely to be a point of reference for successive governments in the coming years and will largely determine their political activity. The extensive nature of the low-carbon transformation likely makes further decarbonization a topic of greater political importance in the coming years, and of growing interest for governments on various levels.

This article shed some light on what the crucial implementation phase of the British low-carbon transformation might look like in the coming years. In particular, it was pointed out that the current state of devolution settlements, including the division of reserved and devolved competences, significantly hinders effective, unilateral actions at either the central or subnational level. Combined with the ambitious climate goals already announced by the UK – which should be further increased in the coming years[28] (supranational level of governance) – and the signalled policy gap problem, this means that devolved administrations will play a key role in the transformation process in years to come. Against this background, IGR – which thus far has played only a limited role due to the aforementioned focus on actions in the mostly reserved energy sector – may gain new importance and dynamics in the coming years.

MLG has proven to be a useful approach to analyzing the UK's climate transition, allowing the reconnection of the seemingly discrete areas of the social sciences. According to Bache and

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[25] *Vide* above all McEwen, Kenny, Sheldon, Brown Shaw, 2020: 636.

[26] A good example of this is the informal Net Zero Scrutiny Group, made up of dozens of Conservative MPs whose aim is to challenge the government's net zero policies.

[27] For example, Brexit or the cost of living crisis.

[28] *Vide* Paris Agreement, article 4.3.

Flinders, MLG "directs attention to a complexity, cross-sectoral engagement, and contestation of legitimate authority between actors organized at different territorial levels, which increasingly speaks of the nature of British governance". However, these authors also point out that "we cannot expect multi-level governance to explain everything in relation to British government and politics but it can aid our understanding of dynamic processes and help us to isolate key variables" (Bache, Flinders, 2004: 94). In other words, the new IGR model should be seen as a step towards increased institutionalization of intergovernmental contacts, potentially giving them a new dynamic, pushing for more regular and meaningful contacts between governments on different levels, especially in terms of creating synergies across the various policy domains. Nonetheless, much will depend on the dynamics of wider UK politics as low-carbon transformation may become a "part of a larger game that politicians are playing" (Greer, Trench, 2010: 511). This includes, among others, the Scottish independence issue or the direction in which British unionism will be heading, in particular the possible implementation of elements of so-called muscular unionism[29].

Recent years have shown that in response to emerging challenges, UK governance changes, as exemplified by common frameworks, created in response to the challenges related to the return of some competences in policy areas previously governed by a common EU law. Keating notes that over time "questions may be asked about why Frameworks are used in that context and not in other areas where there are overlapping powers or common interest" (Constitution, Europe, External Affairs and Culture Committee, 2022). It can be expected that the devolution settlement and IGR will be subject to further transformations and adjustments to the changing political reality in the coming years, especially since, as indicated in this article, not all the existing weaknesses of IGR have been resolved.

Although "devolution was never an attempt to create a better institutional 'fit' (…) to address key policy objectives such as the (then) emergent issues of decarbonization" (Cowell, Ellis, Sherry-Brennan, Strachan, Toke, 2015: 481), the intersection between British climate transformation and the devolution settlement and IGR is noticeable. As Turner observed in 2013, "devolution shaped the national climate governance regime created by the Climate Change Act 2008, but will itself be tested and even altered as the traction of the low carbon imperative intensifies" (Turner, 2013: 203). These spheres are likely to influence each other more strongly in the coming years[30]. Only time will tell whether the new IGR model will bring new dynamics to the relationship between the levels of power in the UK and whether it will be sufficient to enable effective implementation of relevant climate transformation initiatives. Any failures in this regard will add to the broader debate on net zero governance and ideas to establish a new, dedicated institution whose aim would be to coordinate British decarbonization (Net Zero Delivery Body). Such ideas are beginning to resonate more often at the political level, which was exemplified by the Net Zero Review, ordered by the UK Government and published in January 2023 (Skidmore, 2023: 10-11). As indicated in part four of this article, IGR also serve the devolved administrations in preserving and strengthening their autonomies. Possible

[29] Andrews identifies four forms of unionism, *vide* Andrews, 2021: 515-519.

[30] The CCA's systemic nature, expressed values and mechanisms used to defend them in different time horizons, interfering with the scope of freedom of state authorities, led some researchers and politicians to conclude that the Act – similar to the devolution acts – is de facto part of the British constitutional order – vide above all McHarg, 2011: 474-477.

attempts to establish a Net Zero Delivery Body, which by nature of its task is likely to compete for some competences and oversight with devolved authorities, will exert additional pressure on the devolution settlements and highlight the importance of effective IGR as a factor necessary for both successful climate transformation and minimizing the risk of constitutional tensions in the future.

The article does not present the official position of the institution where the author works, but his personal views only. The translation of the quoted Polish sources into English is the author's own.

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Energy recovery from waste as an essential part of a sustainable economy

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Abstract: The article presents an analysis of benefits of the energy recovery from waste. Presented a look at energy recovery from waste as part of a modern and diversified national energy policy. Energy recovery from waste is an essential link in closing the model of a sustainable closed-cycle economy. The paper presents the basic legal regulations on energy recovery from waste in Poland and the European Union and discusses the waste hierarchy model, according to which energy recovery from waste is placed behind material recycling. The technical basis of the energy recovery process in waste incineration plants is presented, as well as the possibility of classifying part of the energy recovered from waste as energy from a renewable source. The importance of cogeneration, regarded as the most efficient way of producing energy from waste, is emphasised.

Key words: waste management, recycling, energy recovery, renewable energy sources, sustainability

Introduction

Waste is any substance or object which the holder discards, intends or undertakes to discard (OJ EU.L.2008.312.3, as amended: Article 3(1)). The generation of waste is inevitable, as it is inherent in the processes of production and consumerism (Famielec 2016: 175). Waste management is a significant environmental problem. With the economic development of countries and the improving quality of life of their inhabitants, the amount of waste is increasing. Waste management is usually associated with disposal. However, waste can be an important source of secondary raw materials and fuels. Considering the total amount of waste generated and its increase over the years, it can be concluded that waste incineration is a potential source of energy. Energy recovery from waste substances is referred to as WtE *(Waste to Energy)* processes. Energy from waste has been successfully recovered in cement plants for many years. In recent years, thermal waste treatment plants have become increasingly popular. Thermal waste treatment is replacing landfill, which is at the bottom of the waste hierarchy as the least desirable waste management method.

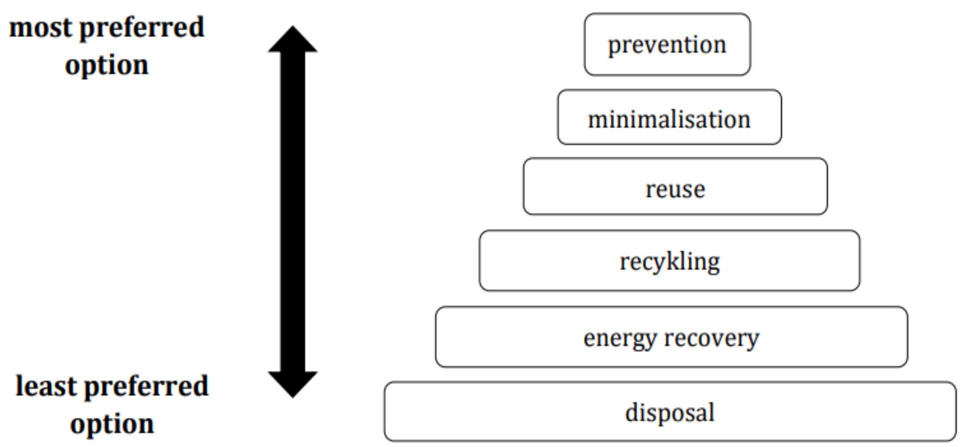
Some of the waste groups with favourable energy parameters contain a biodegradable fraction within them. The energetic use of such waste brings the additional benefit of being able to classify the energy generated, in part from the biodegradable fraction contained in the waste, as coming from renewable sources (Wasilewski, Bałazińska 2018: 130).

The process of thermal waste conversion with energy recovery is economically justifiable and technically feasible, regulated in EU and Polish law (Famielec 2016: 174).

Legislation on thermal waste treatment with energy recovery in Poland and the European Union

Under Article 194(1) of the Treaty on the Functioning of the European Union (OJ EU.L.2012.326.47, as amended), the promotion of renewable energy sources is one of the main objectives of EU energy policy. This objective is implemented by Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (OJ EU.L.2018.328.82, as amended). In this act, European Union Member States were obliged to develop support schemes for renewable energy sources, taking into account the available sustainable supply of biomass, the application of the closed-loop economy principle and the waste hierarchy so as to avoid distortions in the raw material markets. It was emphasised that waste prevention and material recycling are priorities and thus take precedence over energy recovery from waste. It follows from the above that, in the light of the legislation, energy recovery from waste is a less desirable activity than recycling of waste. Therefore, groups of waste that have already been recycled, or for which - for economic or technical reasons - the recycling process is not justified, should be subject to the energy recovery process (Wasilewski, Bałazińska 2018: 130). Fig. 1. shows the waste hierarchy model promoted by the EU.

Fig. 1. Hierarchy of waste management



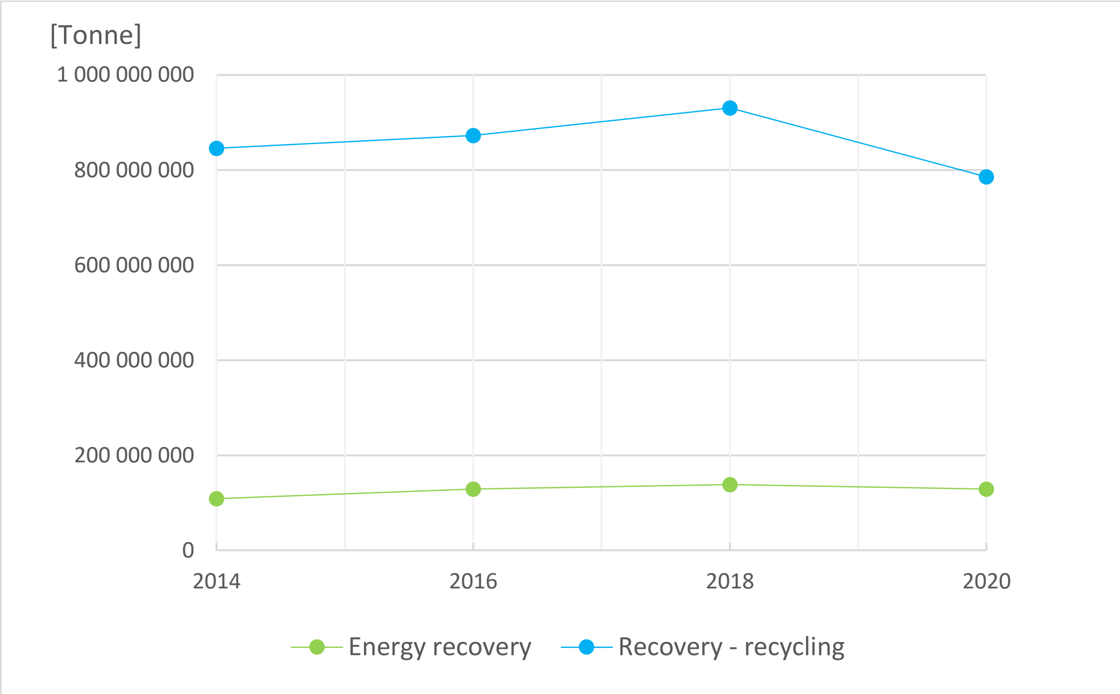
Source: Own elaboration

According to the waste hierarchy model, the most desirable action mechanisms are waste prevention, reduction and reuse. If these actions are not possible, the waste should be recycled. Energy recovery from waste, as a less desirable method than recycling, is ranked just behind it in the waste hierarchy. At the bottom of the presented model is waste disposal, which, as already mentioned, is the least desirable waste treatment method.

According to Eurostat (online data code: ENV_WASTRT), in 2020 in the countries of the European Union, about 60% of the total treated waste was recovered, of which 40% was recycled, 13% was used to fill pits and 7% of the total treated waste was incinerated with energy recovery. The remaining 40% of the treated waste was landfilled and 0,5% was incinerated without energy recovery.

Fig. 2. shows the levels of recycling and energy recovery from waste according to Eurostat data in European Union countries for the years: 2014, 2016, 2018 and 2020.

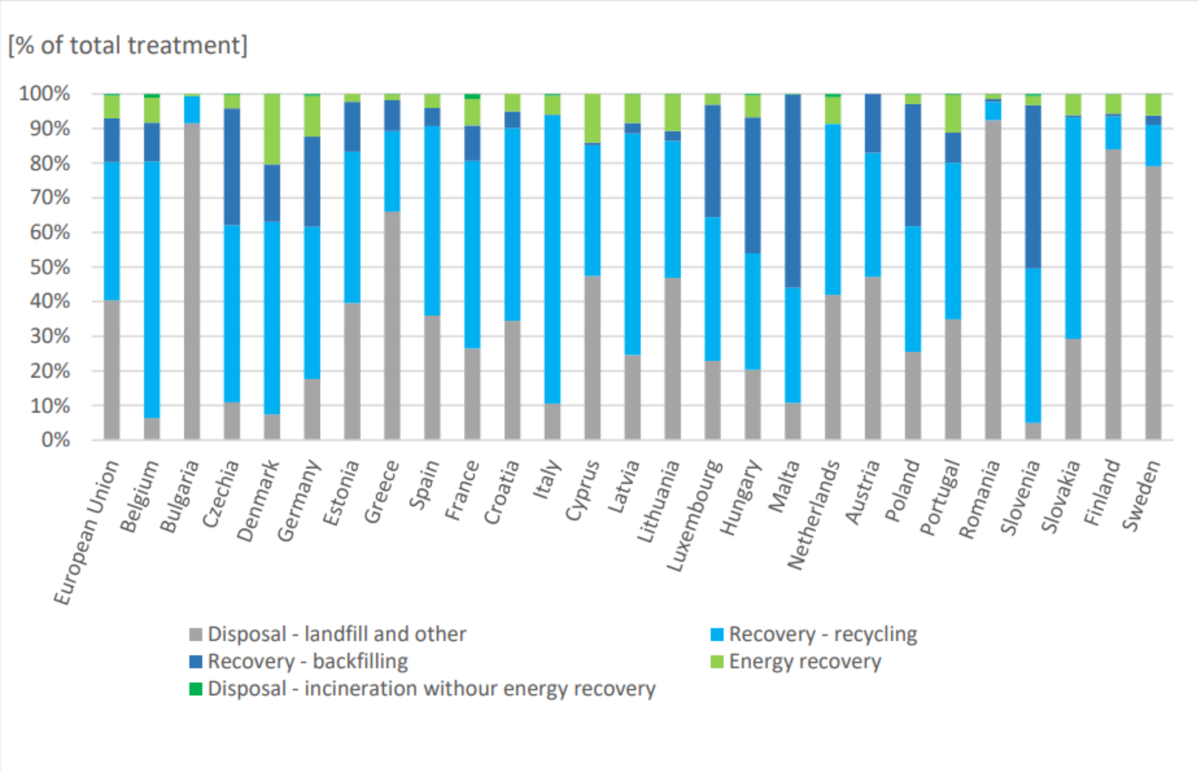
Fig. 2. Levels of achieved recycling and energy recovery from waste in the EU for the years: 2014, 2016, 2018, 2020



*For 2014,2016 and 2018, data are presented for the 28 EU members, for 2020 for the 27 EU members (excluding the UK)
Source: Compiled by the author based on Eurostat.

For both recycling and energy recovery from waste, we can see for 2020 a downward trend in the levels achieved. It is important to remember that in 2020, the Covid-19 pandemic broke out, reducing production and consumption, slowing the development of the world economies. The share of the various waste treatment options in EU countries in 2020 is shown in Fig. 3.

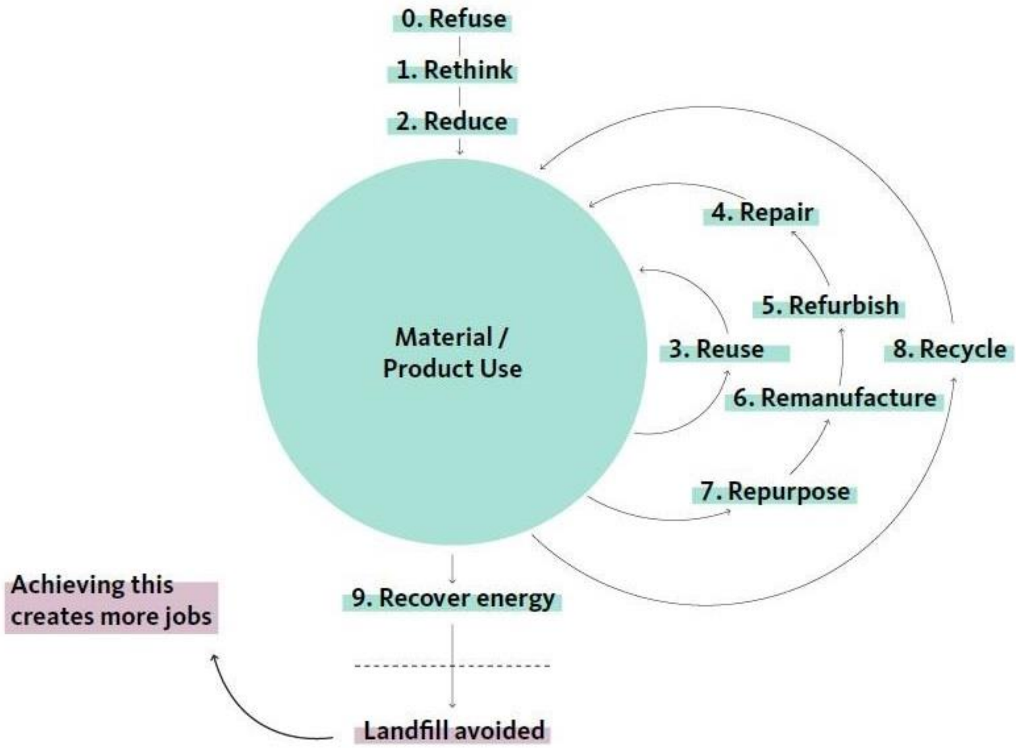
Fig. 3. Waste treatment by type of recovery and disposal in 2020 in EU



*data for Ireland - not available
Source: Compiled by the author based on Eurostat.

The European Union is taking action to protect human health and the environment by setting out a framework for proper waste management, including recycling and recovery. Measures taken to promote a circular economy are intended to reduce demand for resources, use them prudently and efficiently, expand the use of renewable energy, increase energy efficiency, reduce the Union's dependence on imported raw materials or create new economic opportunities.

Fig. 4. Schematic of a closed-loop economy



Source: www.gensler.com/blog/circular-economy-reusing-materials-to-save-cost-lower-carbon

The enacted Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ.EU.L.2008.312.3, as amended) reaffirmed the waste hierarchy, according to which the re-use and recycling of waste takes precedence over energy recovery from waste, if and only to the extent that these are the most environmentally sound methods available. Article 23 of the Directive requires establishments and undertakings that intend to treat waste to obtain a permit from the competent authority to carry out the activity. One of the conditions for carrying out the activity of incineration or co-incineration of waste with energy recovery is a high level of energy efficiency of the process carried out. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (OJ.EU.L.2018.150.109) also placed emphasis on, inter alia, increasing synergies between the closed-loop economy and energy and climate policies, among others.

The waste management system in Poland is regulated by the Waste Act of 14 December 2012 (Journal of Laws 2022 item 699, as amended). According to the definition contained in this Act, thermal waste conversion should be understood as the incineration of waste by oxidation or thermal waste conversion processes other than oxidation, including pyrolysis, gasification and plasma process, as long as the substances generated during these processes are subsequently incinerated. In addition, the Act defines a waste incineration plant as a plant or part thereof intended for the thermal treatment of waste with or without recovery of the thermal energy generated, and waste co-incineration plants as a plant or part thereof whose main activity is the generation of energy or products in which waste is thermally transformed together with fuels for the purpose of recovering the energy contained therein or for the purpose of disposal.

Under the Waste Act, the thermal conversion of hazardous waste and municipal solid waste constitutes a disposal process. In contrast, the thermal treatment, for the purpose of energy recovery, of packaging waste, non-hazardous waste and municipal solid waste constitutes energy recovery.

According to EU law, which has also been implemented into Polish law, it is prohibited to landfill waste whose heat of combustion exceeds 6 MJ/kg. Such waste that cannot be recycled can be diverted to an energy recovery process (Pikoń, Bogacka 2016: 123).

The basis for qualifying energy generated from waste as coming from a renewable source is the content of the biodegradable fraction. This issue is regulated in Polish law by the Regulation of the Minister of the Environment of 8 June 2018 on the technical conditions for qualifying the portion of energy recovered from thermal waste conversion (Journal of Laws 2016 item 847). There are two ways of determining the share of renewable energy, i.e. on the basis of direct measurements of the content of biodegradable fractions in the tested waste or taking into account the relevant lump sum value of the share of chemical energy of biodegradable fractions (for certain types of waste listed in Annex 3 to the Regulation).

Technical basis of energy recovery from waste. Energy efficiency of thermal waste treatment plants

Energy is extracted from waste through thermal conversion, mainly by incineration. However, some fractions can be subjected to methane fermentation - this process results in high-energy biogas (Pikoń, Bogacka 2016: 120).

Methods of recovering energy from waste include:

- the thermal treatment of waste, i.e:
  - combustion,
  - pyrolysis,
  - gasification, and
- biogas production by methane fermentation from biodegradable fractions.

Waste incineration takes place in specially designed thermal waste conversion plants, commonly referred to as waste incineration plants (Cyranka, Jurczyk 2015: 33). The financial outlay needed to build a thermal waste conversion plant can be a major problem when starting to build a new facility. Profit from operating a plant may only emerge after several years or even several decades of operation. Sources of revenue include fees charged for waste disposal, the sale of electricity and heat, and the sale of iron or scrap non-ferrous metals recovered from the slag and fly ash (Pikoń, Bogacka 2016: 121). The construction of new facilities also creates new jobs.

Thermal waste treatment plants operating in the EU are subject to stringent standards, which means that modern installations, covered by a system of constant monitoring of pollutant emissions, can confidently be regarded as completely safe for people and the environment.

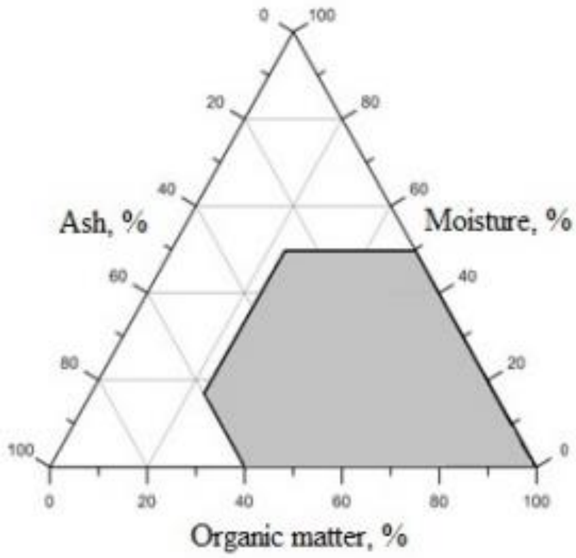
The recovery of energy from waste depends on the use of a number of installations and facilities to ensure that the combustion and energy conversion processes can take place properly. In addition to the energy recovery segment, which includes, among others, the boiler, turbine, condensers and heat exchangers, the design of such a plant should also include other installations and equipment designed, in particular, to receive and collect delivered waste, treat flue gases or manage solid residues (Cyranka, Jurczyk 2015: 35).

The physical and chemical properties of the waste delivered to the plant determine the selection of appropriate technologies, as well as the degree of efficiency of the waste incineration process. The most important parameter that determines the amount of energy that can be produced from 1 Mg of waste is its calorific value. It defines the suitability of matter for use in the energy sector (Jędrzejowski, Latosińska et al. 2018: 358) and denotes the amount of energy (heat) released during the combustion of a unit of mass, or a unit volume of fuel, expressed in [MJ/kg]. The calorific value depends on the proportion of combustible parts, mineral matter and moisture. The calorific value of a fuel decreases with increasing moisture, which is often a result of the storage and transport conditions of that fuel, as well as its pretreatment (Wasielewski, Stelmach et al. 2015: 116).

A key issue is the autothermicity of the combustion process, meaning the ability to burn waste without introducing additional energy. Autothermic combustion of waste is assumed to have a calorific value of at least 6 MJ/kg. In addition to the calorific value, the autothermicity of combustion processes is also influenced by the proportion of: combustible parts, non-combustible parts and moisture in the waste. Using Tanner's triangle, the area of autothermic combustion can be determined for a given fuel. On its individual axes, the percentages of the parameters: combustible parts, non-combustible parts and moisture are plotted (Famielec 2016: 179). It can be seen from the Tanner diagram shown in Fig. 4 that the autothermic combustion area is taken to be the area (circled in grey) bounded by the proportion:

- combustible parts min. 25%,
- non-combustible parts max. 60%,
- moisture content max. 50%.

Fig. 5. The Tanner diagram



Source: Wilk M., Magdziarz A., An evaluation of rewenable fuels microstructure after the combustion process, Journal of Power Technologies 97(4) (2017) 265-271.

The energy efficiency (a.k.a. efficiency) of a waste incineration plant compares the value of the input chemical energy contained in the waste with the energy recovered from the waste, i.e. the electrical and thermal energy produced (which has not been dissipated, e.g. by flue gas, radiation, cooling system) (JRC Report: 259). The energy efficiency of the recovery process determines the environmental benefits that the process can provide. Adequate energy efficiency in the recovery process depends to a large extent on the construction of the thermal waste treatment facility and its operation in such a way as to guarantee optimum recovery, i.e. that the maximum amount of energy is obtained without endangering the environment. The plant in operation must meet BAT - *Best Available Techniques* - requirements, thus guaranteeing the highest environmental standards.

The most desirable way to do this is to operate the plant in a cogeneration process *(CHP – Combined Heat and Power)*, which produces electricity and heat simultaneously. Cogeneration is a highly efficient process - the overall efficiency exceeds 85%. A unit operating in cogeneration system is characterised by a lower fuel requirement than in the case of separate electricity and heat production processes (Cyranka, Jurczyk 2016: 103-104). In a traditional power plant, heat is converted into electricity. During the process, more than half of the power is lost. A modern combined heat and power plant operating in cogeneration units uses waste heat generated in the production of electricity. Thanks to the cogeneration operation, savings in the purchase of electricity can even exceed 40%. According to the estimates financial outlays for the investment can be returned after about 3 - 4 years (HNL). In addition, the use of cogeneration has a significant impact on the environment, such as the reduction of greenhouse gas emissions.

Energy generated in cogeneration can be considered as electricity generated in high-efficiency cogeneration, provided that the cogeneration unit PES *(Primary Energy Savings)* achieves:

- PES ≥ 10 % - for installations with a capacity above 1 MW;
- PES ≥ 0 - for installations with a capacity less than or equal to 1 MW.

Optimisation of recovery process techniques requires plants to be designed to meet the requirements of consumers. It is clear that plants that supply only electricity will be designed differently from those designed to supply only heat. Plants that are intended to supply both electricity and heat will also be designed differently (JRC Report: 327).

Only the right waste resource, as well as an optimal and stable source for the energy produced, is a guarantee for the stability, availability and energy efficiency of the operation of a thermal waste treatment plant. The importance of physical and chemical properties of waste should be emphasized, especially waste containing high-calorific combustible fractions (>6 MJ/kg), which ensure stable operation of installation, with the highest possible recovery efficiency. The most important factors determining the way and effectiveness of the integration of waste incineration plants into the local infrastructure are:

- availability of the power grid,
- demand for the energy produced,
- reliability of the energy source and adequate supply of waste,
- waste composition,
- the level of local prices for electricity and heat (Cyranka, Jurczyk, 2015: 40).

Thermal waste conversion technology should be characterized by low energy consumption and high-efficiency energy conversion and production. In the case of facilities converting only municipal solid waste, the installation should maximize the use of recovered energy to such an extent that the energy efficiency of the installation reaches a level that allows it to obtain the legal status of an installation implementing recovery process R1 (use mainly as a fuel or other means of energy production), according to the criterion indicated in Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance), where the average annual energy efficiency factor reaches a minimum value of 0,65 for installations permitted after 31 December 2008. The energy efficiency is then determined from the formula:

$$Energy\ efficiency = \left(E_p - \left(E_f + E_i\right)\right) / \left(0{,}97 \times \left(E_w + E_f\right)\right)$$

In which:
E_p - annual energy produced as heat or electricity. It is calculated with Energy in the form of electricity being multiplied by 2,6 and heat produced for commercial use multiplied by 1,1 (GJ/year)
E_f - annual energy input to the system from fuels contributing to the production of steam (GJ/year)
E_w - annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)
E_i - annual energy imported exluding E_w and E_f (GJ/year)
0,97 - a factor accounting for energy losses due to bottom ash and radiation.

This formula shall be applied in accordance with the reference dokument on Best Available Techniques for waste incineration (OJ EU.L.2008.312.3, as amended: Annex II, Recovery operations). However, it is important to remember that higher process energy efficiency also leads to higher investment and maintenance costs.

Recycling is much less capital-intensive than incineration and often does not need modern technological solutions. The principle of recycling is to maximise the use of waste materials while minimising the input into their manufacture. The energy consumed in the process of making the products in question from primary raw materials will generally be greater than if they were made from secondary raw materials. However, the preparation of the input itself, by which is meant the collection and sorting of waste, can also be costly and energy-intensive (Pikoń, Bogacka 2016: 122).

The gateway to energy security through energy recovery from waste

Energy security is a priority for modern states, both economically, politically, environmentally and socially. The promotion of renewable energy sources is without a doubt among measures conducive to enhancing energy security. Their use affects a country's greater independence from the supply of raw materials (Seroka 2022: 88).

The European Union aims to ensure that citizens and businesses have access to energy that is *'secure, affordable and environmentally friendly'*. Its actions relate to promoting energy efficiency, diversifying energy sources or strengthening the share of energy from renewable sources. The closed-loop (zero-waste) economy promoted by the EU is part of the principle of sustainable development, contributing among other things to reducing the extraction of fossil fuels. Ways of preventing landfill are recycling and energy recovery. Disposing of waste to landfill diminishes the raw material and energy potential of EU countries. The operation of thermal waste treatment facilities with energy recovery counteracts the proliferation of landfill sites and helps to increase Europe's independence from fossil fuel imports, thereby contributing to strengthening energy security, which is in line with the main objectives of EU energy policy (Ecogenerator).

Summary

One of the inevitable consequences of the development of civilisation is the increase in the amount of waste produced. The more developed a country is, the greater the problem becomes. However, economic development must be compatible with environmental protection requirements (Dziolak, 2010: 649). The perceived energy potential in waste has made it possible to look at the problem of waste management in a somewhat softer way. The benefits of waste-to-energy are many, both ecologically and economically. The environmental benefits of recovering energy from waste include reducing the need for fossil fuels, which are non-renewable fossil fuels. The energy use of waste also contributes to reducing the number of landfills, including preventing the dumping of waste with high calorific value. Disposal of waste using traditional methods is a source of significant emissions of harmful gases, especially methane and carbon dioxide. Obtaining energy from waste reduces greenhouse gas emissions and thus counteracts climate change. Some types of waste with favorable energy parameters also contain a biodegradable fraction. The energetic use of such types of waste provides the basis for qualifying the generated energy as coming from renewable sources and leads to an increase in the share of RES in the energy mix. From an economic point of view, it can be said that the energetic use of waste can contribute to lower energy prices and waste management fees. It also creates new jobs. Thermal waste conversion is a good solution, but on condition that the thermal waste conversion plants are operated sustainably, with energy recovery. Such projects in the most developed countries of Europe are already a permanent part of waste management and also a permanent part of the energy industry. The use of waste for energy recovery can certainly be considered a desirable element of any country's energy policy and as a necessary link to closing the model of a closed-loop economy. Technological progress makes it possible to convert waste, in modern installations, into high-quality energy carriers, with no burden on the environment. The most efficient energy recovery is considered to be the cogeneration process, which simultaneously produces electricity and heat. The amount of waste generated and the requirements imposed by the EU make the expansion of energy recovery infrastructure from waste necessary and desirable (Cyranka and Jurczyk, 2016: 99).

What is needed is to increase public awareness and environmental education about the operation of thermal waste conversion plants and to dispel public doubts about the safe and non-hazardous operation of this type of plant.

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Algae as an alternative to the methods of production and use of conventional biomass (review article)

Piotr Plata

Abstract: Algae have been present in the water treatments technologies, food for animals makingprocesses or even for diet supplements production for many years now. Recent years, however, have brought a number of ideas and discoveries for a wider use of these autotrophs. Their use is related to the broadly understood environmental protection and many threads of combating climate change. Currently, one of the most common ways of using algae is the production of liquid biofuels of the 3rd and 4th generation and unconventional biomass generation. Biofuels obtained from algae, in addition to lower amounts of harmful substances contained in them, are often characterized by a negative emission balance. It is related to the fact that those organisms, being in an exponential growth phase, assimilate the carbon dioxideneeded for photosynthesis. The production of energy substances from algae and microalgae in the teeth of draining fossil fuel deposits and their destructive impact on the environment. That sooth combined with the ease and low cost of culture, condition they become a real alternative to existing energy sources. Unique properties of algae linked with the fact that they are among the best, known biological energy converters opens the way to a number of opportunities to use them in other economic sectors. Certainly, the technological revolution in the energy market in addition to the requirement to create the most efficient reactors, in-depth research on the properties of fuels and the producers themselves still needs to be regulated by law. Algae can be grown in polluted waters, and the energy raw materials produced from them are able to reach (without emission logistic costs) a negative balance of CO_2 emissions. This phenomenon and the fact that apart from fuels and biogas, they can be used for purposes such as carbon sequestration, creating energy biomass, medicines and dietary supplements, as well as food for animals, for example, the most reasonable choice would be to create advanced regulations regarding the closed- circuit policy in the energy sector, based precisely on biologically active organisms. This work focuses on gathering and presenting basic information regarding current technologies related to algae, their potential uses in the energy sector, and the long-term prospects for their development. It also takes into account the issues associated with the holistic nature of energy harvesting methods such as the one discussed.

Key words: algae, bioeconomy, biofuels, biorefinery

Introduction

Already in 2007, the IPCC published a report in which scientists estimated that with 90% probability global warming has no temporary nature and that climate crisis is largely caused by human activities (IPCC, 2007). These activities cover many issues, however the extraction of fossil fuels and the generation of energy from them is one of the main drivers of greenhouse gas emissions. And as we know, it is they that cause the increase in the average global temperature.

In order to better understand the problem of amount of carbon dioxide emitted, it is worth looking at couple of figures and putting them together (Dubiński et al., 2010: 3):

– The burning of fossil fuels emits about 10 billion metric tons of carbon dioxide each year.

– Oceans absorb 1.6 billion tons more CO_2 than they produce themselves

– Soils and all vegetation absorb 3 billion tons od CO_2 more than they produce.

It can be noted that every year about 5.4 billion tons of carbon dioxide remains in the atmosphere, coming only from the combustion of traditional fuels. What compounds the magnitude of the surplus of carbon dioxide in the atmosphere is that the burning of fossil fuels is responsible for less than 30% of all human-related CO_2 emissions (2008 data) (Dubiński et al., 2010).

The whole problem and its origins are very complicated and the issue of changing and improving the global situation is very complex. Nevertheless, improving the processes of extracting energy from fossil fuels such as oil or coal or patenting new ways of producing energy seem to be steps that will significantly slow the warming process and halt some of the adverse environmental changes. Recent estimates show that global energy demand will increase by about 30% over the next 18 years. (United Nations Data) Because of predictions, close to certainty, that electricity will be the dominant energy carrier, modern solutions are already being implemented to improve the efficiency, cleanliness and integrity of the entire energy system. In the face of projected global energy demand in the coming years, one of the most economically important technological issues is to provide citizens and industry chains such energy with simultaneous as little harmful impact on the environment and climat as possible.

The hope here is renewable energy sources, which are capable of providing us with much cleaner energy than fossil fuels (Kozłowski, 2019: 2-3).

Renewable energy sources (RES) are an alternative to traditional, primary, non-renewable energy carriers (fossil fuels). Their resources are replenished by natural processes, which practically allows to treat them as inexhaustible. In addition, obtaining energy from these sources is, compared to traditional (fossil) sources, more environmentally friendly. The use of RES significantly reduces the harmful impact of energy on the environment, mainly by reducing emissions of harmful substances, especially greenhouse gases (IEA and United Nations).

In the widely held for years debate on climate change and the possibility of combating global warming the role of biomass is extensively discussed. Many scientists pin their hopes on it asa source of clean and fully renewable energy. Its high calorific value combined with ease of production and low cost is making energy derived from biological resources andenvironmental waste increasingly popular. Of course, the production of biomass material mustnot compete with food crops, and the use of agricultural fields for energy crop production is just such a competition. Scientists, over the years, have been able to study and modify some plants in such a way that their production can take place on poor quality soils (Jęczmionek, 2010: 7).

Biomass material gaining in popularity are algae and microalgae. This is due to their ease of breeding, their exceptionally good biomass performance as a direct combustion product, and by their wide range of uses to create or refine other energy feedstocks.

Characteristics of algae

Algae are microscopic, often single-celled organisms that inhabit the aquatic environment. They constitute a highly diverse group of eukaryotes and procaryotes (Kumar et al., 2010: 2-4) (Khani, 2018: 1), inhabiting widely differing aquatic territories (Skjånes, 2012: 2-3) (Khani, 2018: 1-2),. So far, about 300,000 species of these organisms have been recognized, but their number is estimated to be at least hundreds of thousands (Alam, 2015: 2-3). Individual species of algae differ from each other, often even significantly. However, they are united by a number of features, which make them unique and may in the future constitute one of the basic rungs of the energy revolution. They contain sizable amounts of proteins, nucleic acids, carbohydrates, mineral salts and fats (up to 77% of dry weight) (Shroeader et al., 2013: 3). They are able to thrive in both saline and fresh surface waters. These microorganisms are autophototrophs, using solar energy and carbon dioxide and mineral salts for their own development and growth (Chisti, 2020: 3). What distinguishes algae from other biomass sources is their very rapid mass gain and the fact that they are among the best natural converters of solar energy on earth (Subhadra, 2011: 1-4).

As photosynthesizers, these organisms living in huge amounts in the oceans, together with photosynthetic bacteria and photoplancton are responsible for 50% of the oxygen that is found in our lungs with every single breath (National Ocean Service data). It is thanks to them that we say the oceans produce such huge amounts of respiratory gas. Despite their huge contribution to the entire biosystem of planet Earth, they have no organs or qualified internal structures. Nor do they form specialized cellular formations such as leaves or roots. Their phenomenon focuses on chlorophyll and mechanisms for converting sunlight into energy, food and building compounds. These organisms, despite their small size and marginal cultivation requirements, are characterized by a huge ratio of biomass to volume and an extremely rapid process of photosynthesis, which makes them one of the best converters of solar energy on Earth.

Algae have been known to man for hundreds of years. Today, these organisms are grown on alarge scale mainly for the pharmaceutical and cosmetic industries. However, the fact of high content of proteins, amino acids or various elements makes the possibilities of using algae much greater. For several years, the energy sector has been looking to algae - as a source of biomass and substrates for the production of energy raw materials - as a solution to the problems generated by traditional, fossil energy sources.

A breakthrough in this field turned out to be the discovery of biofuels and their potential. These are alternatives to petroleum-based energy sources for, among other things, widespread transportation. The development of this field of technology has caused scientists to come across algae as a substrate for the production of just such chemical compounds. Theseorganisms are characterized by higher photosynthetic potential than plants (Maojidek, 2021: 1,23) (Alam, 2015: 2) and, in addition, are rich in various types of lipids. Fats constitute, under certain conditions and for a certain species, up to 77% of the dry weight of a microalgae cell (Shroeader et al., 2013: 3). It is likely that this characteristic, combined with cost-effectiveness and simplicity of production, proved to be a significant factor in assessing the suitability of algae for the energy sector, with transportation fuels emphasized.

Algae have become the subject of much research over time, both in terms of technology and processes for growing them. They are a common laboratory material even in technical universities. This whole cognitive branch of science and technology has solved some of the problems that were posed by energy crops bred for the production of first and second generation biofuels. Plants that are their primary source, namely oilseed crops, often withquite high soil requirements, were considerable competition for food grown around the world.This aroused a conflict of interest for large companies that competed for farmland with fertile soil (Tudge, 2021: 13-15) (Mahmood, 2023: 14,15). What is more important, that issue started the discussion on the ethical aspectsof such an phenomenon. The seizure of land for food production, whether for animals or humans, at a time of hunger crisis in some parts of the world, was definitely not a positive sign.

Thus, the potential of algae has been recognized at the right time, and the development of research and technology makes it possible to look at them optimistically as a solution to many existing problems. First of all, algae are a great competitor for energy crops (Mata 2010). Some estimates suggest that it is possible to obtain 7-31 times more biodiesel from algae oil than from rapeseed oil (palm oil, in this case) (Demirbas, 2010:1). Others, also show that from one acre of land occupied by algae, it ispossible to obtain 30 times more energy than from soybean crops (Datta, 2019: 6).

An additional advantage of algae is the amount of space used to produce them. Cultivated fields occupy huge areas, requiring nurturing, tending or watering, and the harvesting process itself also takes a lot of time in accordance with the area. Algae and microalgae are grown in photobioreactors with huge capacities, but multi-layered - in suspension. The only prerequisite is to provide them with access to light and to properly design the culture system. In this way, from the same usable area we are able to obtain higher yields of algae. This phenomenon is further compounded by the fact of their very rapid growth, the lack of seasonality of breeding and their relatively easy processing.

Algae are organisms that can tolerate very high levels of carbon dioxide, which opens up a range of applications for them. They can not only be a substrate for biomass production but also be CO2 sequesters themselves (Singh, 2011: 5). In the era of emissions trading, this could be a worthwhile solution. Algae cultivation near large industrial plants, in closed loop systems, canbring many environmental and financial benefits (Dismukes et al., 2008).

Those organisms additionally do not require crystal clear water (Rahman, 2020). Post-process liquids, after removing any azatoates, phosphorus or ammonium nitrogen, can be used to fill photobioreactors. This is undoubtedly a huge advantage for plants wishing to introduce closed-loop circuits in their production processes. Algae, as a source for the production of oils competitive to those obtained, for example, from rapeseed, have another extremelyimportant advantage. It is their emission balance. When a kilogram of algae-derived biomassis produced, 1.83 kg of carbon dioxide is absorbed from the air (Dragone et al., 2010: 4).

III and IV generation of biofuels

Undoubtedly, the energy revolution has been part of the Industry 4.0 revolution for years. In addition, with The Paris Agreement signed by 194 countries (Paris Agreement, 2015), huge challenges have been posed to the entire sector, both socially and technologically. Today, highly developed countries are already entering the stage of introducing Industry 5.0.

The assumptions of this revolution are primarily - further networking of machines, transferring their synergies to the Internet but also, or primarily - further economic growth, but in balance with the environment. This prerequisite, not directly, but nevertheless, puts emphasis on technologies for energy extraction, processing and distribution.

Knowing that electrification of all transportation is not feasible without excessive exploitationof the environment (Pitron, 2018), due to small deposits of rare earth elements relative to demand, it becomes the responsibility of companies in the energy sector to develop other options. One of these is the development of biofuel technologies. Their current market is mostly associated with bioethanol and biodiesel. These are first- or second-generation fuels, depending on the material from which they are produced. The criterion that divides biofuels into first-generation or second-generation is whether they were produced from food crops or oil crops, but not in any way a source of food - whether for animals or human.

The proliferation and presently prevalent adoption of these biofuels has been an undeniable success. Names such as biodiesel have even become widely understood terms. However, there are many more types of first- and second-generation biofuels. Beginning with bioethanol in various forms, PVO vegetable oils, before FAME methyl esters and FAEE ethyl estersdescribed as biodiesel, and ending with products of secondary processing of biofuels - bio- ETBE formed from bioethanol refined (Biernat, 2012: 1-3). The most important aspect, however, in the whole socio-economic transformation seems to be educating people with the simultaneous introduction of technologically and ideologically improved processes. Such technologies can be characterized by processes for the production of third- and fourth-generation biofuels.

In the general terms, these biofuels are fuels produced from algal biomass, the cultivation of which takes much less space than is needed to obtain the same amount from lignocellulosic plants (Brennan et al., 2010). The main biofuels derived from algae are bio-ethanol and biodiesel, but biohydrogen production technologies are becoming more common.

Undoubtedly, a positive phenomenon is the growing interest in their topic in recent years. Biofuels created from algae seem to be a solution to some of the problems that today's economy is facing. First of all, there is the problem of cultivating energy crops.

The biofuel market is constantly growing, and the use of alternative fuels to petroleum is becoming more widespread. Until now, the only source of oils used as substrates for biofuel production has been plants - often food crops. This gave rise to first-generation biofuels. However, when it was realized that using plants intended for food purposes to produce fuels raised moral conflicts, energy plants were patented. They are not used for producing food for animals or humans, but this does not change the fact that farmers compete for fertile land to obtain the highest possible yields. Competition between the food production sector and theone responsible for the creation of fuels also raises many controversies.

Of course, there are energy plants that do not require highly fertile soils and are even able to grow on marshy or clayey terrain - an example is Camelina Sativa, whose oil in many countries (mainly Germany and US) (Jęczmionek, 2010: 2-3) is an alternative to rapeseed oil for biodiesel production. However, comparing the possibilities of utilization, the surface area used for production, or the carbon footprint, the competition between higher plants and algae leaves nodoubt. Algae growth takes much less time and cultures are not dependent on the seasons. Withthe use of algae for biomass production, fields of crops remain available to those in the food sector. In a situation where people in various corners of the world, often where energy crops are grown, are suffering from hunger, this is a much-needed solution (Lam, 2012).

Both third- and fourth-generation biofuels are classified as advanced fuels, i.e. those whose development is currently expected to bring tangible results only in the future. This is due to the fact that biofuels extracted from algae are able to absorb carbon dioxide from the atmosphere (Park et al., 2012: 2) (Dragone et al., 2010: 4). This is a process that is invisible to the bare eye in real time, but we can expect environmental improvements on a global scale, assuming full-scale deployment ofsuch fuels.

Their cultivation and processing is generally technologically difficult (Alam, 2015: 3). Due to temperatures oscillating between 20-30 degrees which are required for their growth, these organisms cannot be grown anywhere on earth. However, providing them with the optimum development conditions, this technology is becoming very promising for the development of the fuel sector. All this is due to their tremendously rapid growth. Deserts are a place strongly considered in the context of growing algae there. This is due to the huge amount of light available in these areas for a large part of the day (Singh et al., 2021). In fresh culture, which is in an exponential growth stage, algae can double its population in 24 hours. Thus, algae are cultured in huge open tanks resembling reservoirs. Such a photobioreactor operates on the principles of semi-continuous breeding from which fresh biomass is collected on an ongoing basis (Amini, 2020: 5).

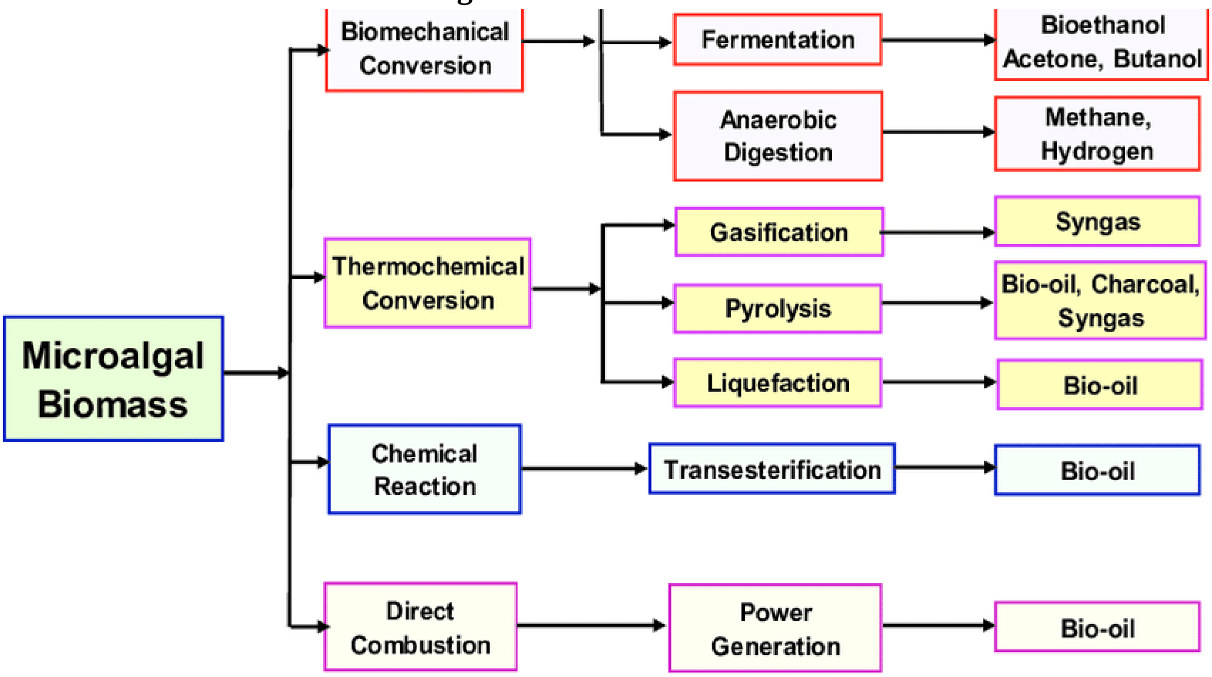
In addition to open cultivation tanks, closed-loop systems are also used to protect algae cultures from contamination. These are generally large cultivation ponds that are separated from the atmosphere. However, this method is less cost-effective due to the need for additional equipment to supply carbon dioxide. The material used must also be a barrier against pollution while allowing light to pass through as efficiently as possible.

The most advanced method of cultivating these organisms is through specially designed photobioreactors. These technologically advanced systems are the most expensive option for cultivation and are not the best solution for economic production facilities, but rather for research and experimental purposes. These reactors mainly serve to understand mass transfer mechanisms, which are fundamental in obtaining biomass from algae (Datta, 2019: 6).

An additional issue is the technology of harvesting and concentrating algae from cultivation tanks, which involves drying, sieving on special screens, and various types of extractions. An additional promising technology for collecting and thickening algal biomass is a special foam column that uses a special surfactant, CTAB, which acts as both a collector and foamingagent (Al-Hemeri et al., 2022: 1-2).

Algae culture sites use both those that are autotrophs and chemotrophs, whose metabolic mechanisms differ. To further increase the already high lipid content of algal dry matter, nitrogen starvation technologies are used (Singh, 2011). The bio-oil obtained in such a scheme is thus a better material for biofuel production. This is due to the presence of more triacylglycerols (TAGs) which are the most important of the substrates for biodiesel production (Meng J. et al., 2009: 1,3).

Scheme 1. Use of biomass from algae



Source: Mobin, 2012: 8.

Currently, advanced biotechnology and genetic engineering methods allow for the improvement of algae. As a relatively well-known genetically and simple group of living organisms, they can be subjected to various modifications. This has led to the development of the fourth group of biofuels, which are obtained from biomass derived from algae that have undergone genetic modifications (Lu et al., 2011: 4-8). Their production is supposed to be based on CCS - carbon capture and storage principles. This applies not only to the algae themselves, but alsoto the technologies used in the entire logistics cycle related to this generation of biofuels. The ultimate goal is to create a range of solutions that will incorporate carbon sequestration in many areas of the economy.

Such a procedure aims to address the emissions that the world is currently facing. This means that in the case of fourth-generation biofuels, engineers want to achieve a completely closed cycle that serves not only the production of biofuels and other cycle products but also the absorption of excess carbon dioxide from the air and its conversion into biomass.

Fourth-generation biofuel technologies include, among others, the following technologies (Lin et al., 2021: 2-4):

– SOLAZYME, which involves non-solar production of JET fuels from algae oils obtained from organisms grown on sewage or agricultural sludge.

– SOLENA, which is based on the production of diesel and advanced JET fuels rough theplasma gasification of waste biomass.

An additional element being developed in the area of third and (primarily) fourth-generationbiofuel production is biorefineries.

Biorefineries in closed loop economy

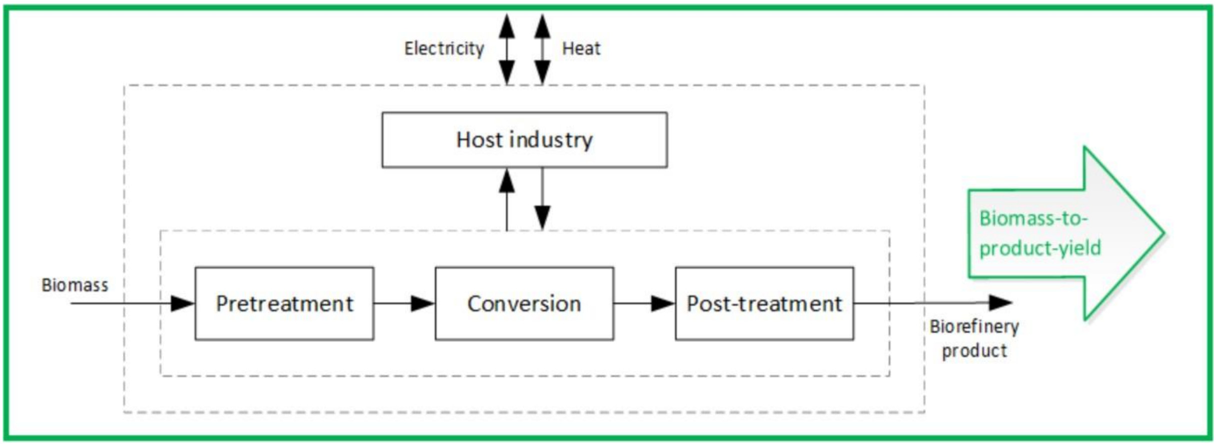
Biofuels, as products obtained from algae cultivation, are considered as a long-term goal. However, currently, the greatest emphasis is placed on the development of other methods utilizing algae to address issues related to low emissions and the fight against the climate crisis.

In recent years, bioeconomy has definitely marked its presence among traditional economic and technological models. Its foundation lies in the utilization of green, low-emission energy sources, which are intended to be used to produce products with the lowest possible impact on the natural environment (Maciejczak et al., 2013: 2-4). The idea behind bioeconomy-based systems is to ensure energy stability and security, to move away from traditional fuels and to significantly improve the climate situation affecting the whole world. The guiding idea behind the technological advancement and implementation of bioeconomy is cooperation and the exploitation of nature and techniques such as biotechnology for its careful use and responsible processing for one's own purposes (Rathore, 2016: 3).

When talking about algae, it is impossible to overlook two important issues. The first is the blue bioeconomy, which is a model based on the production of energy and fuels from living marine resources such as algae, sponges, etc (Wijffels, 2008: 2,6). The second issue is how the goals of the blue bioeconomy are to be achieved. This method involves the introduction and popularization of closed-loop systems (Schoenmakere et al., 2018: 17,33). These systems, based on the utilization andprocessing of their own waste, as well as the use of other renewable energy sources for production, are intended to have a positive impact on the overall operation of the national economy and, in the longer term, the global economy. Job creation, technological development, urban integration, and collaboration among local communities are just some of the benefits brought by this energy model (Geng et al., 2019). The use of closed-loop systems is one of the most common paths to achieving sustainability for farms and manufacturing plants (Horvath et al., 2019: 1-2).

An integral part of closed-loop farms and businesses are biorefineries – the utilization of certain marine organisms, mainly algae, to collaborate with specific production stages. Biorefineries, by definition, are "systems that combine biomass conversion processes and devices for its processing into a single facility producing chemicals, fuels, and energy" (Harasym, 2011: 1) (IEA Bioenergy Task 42). It is also important to note that biorefineries involve a shift from the traditional linear economic model of extraction and disposal, to a modern bioeconomic system that emphasizes remanufacturing, reuse, and processing to achieve climate goals while ensuring continuous economic growth (Carus et al., 2018) (Jørgensen et al., 2018: 37,39).

Scheme 2. A simplified scheme of operation of a biorefinery



Source: Zetterholm et al., 2020: 8.

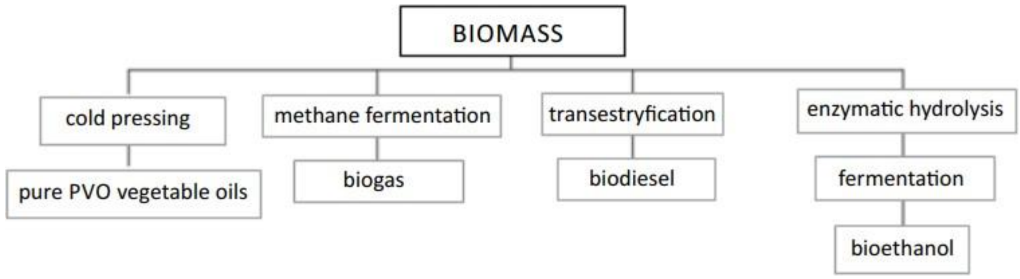
This model ensures better disposal of waste by converting it into usable energy or returning it to the power grid. However, cost reduction is not only associated with self-energy production. The processing of waste results in a significant utilization of a large part of it, and the by-products of these transformations, which are not needed for energy production, often serve as excellent nutritional components for animal feed, making them a marketable product.

The utilization of microorganisms for wastewater treatment is one of the earliest applications that have been developed and implemented on a technological scale. One of the first installations of this kind was built in California, based on the assumptions and analyses of Professor William Oswald's team (Fernandez et al., 2017: 5).

These processes generate enormous amounts of algal biomass, which can be further processedin subsequent stages (Olguin et al., 2003) (Flesch et al., 2013: 2) (Jebali et al., 2018: 1). In addition to using living microorganisms as a source of biomass for further processes, biorefineries can utilize lignocellulosic materials (Kajaste et al., 2014: 1,7) such as agricultural residues, municipal waste (Horvath et al., 2019: 6), and by-products from sugar processing.

Processes like hydrothermal carbonization (HTC) allow to produce heat, biochar, and even drop-in biofuels from biomass obtained from biorefineries (Heilmann, 2010: 1-3). HTC is one of the most efficient and technologically advanced method for converting biomass of various origins into energy products or bioenergy directly (Maniscalco, 2020: 16). Other processes applicable in biorefineries includepyrolysis, fermentation, gasification, enzymatic hydrolysis, and more (Zabed et al., 2017: 11).

Scheme 3. Possibilities of using biomass



Source:own elaboration.

Depending on the goal of a biorefinery, several operational models can be distinguished (IEA Bioenergy Task 42, 2022):

– Energy-driven (or biofuel-driven) biorefineries: These systems aim to produce energy, cogenerate, or recover energy from waste materials. However, this is the least economically viable pathway for biorefinery utilization. It requires significant financial investments and the adaptation of the energy market to accommodate the reception, settlement, and distribution of energy produced by prosumers (Leong et al. 2021: 7,11).

–.Product-driven biorefineries: These biorefineries focus on processing biomass to obtain smaller quantities of high-value-added products that can be used in various sectors of the economy to produce different types of energy. Common products derived from such installations include chemicals like drop-in biofuels and biochar. The utilization in this case is much broader. Besides heat/electricity generation, these substances can be used for carbon capture in the transportation sector (HanPark et al., 2012: 4-5) or carbon sequestration in soil (Bhuiya et al., 2016).

Additionally, biorefineries can be distinguished based on the feedstock used, which correlates with the category of biofuels produced from such installations. As in the case of biofuels, biorefineries are built for:

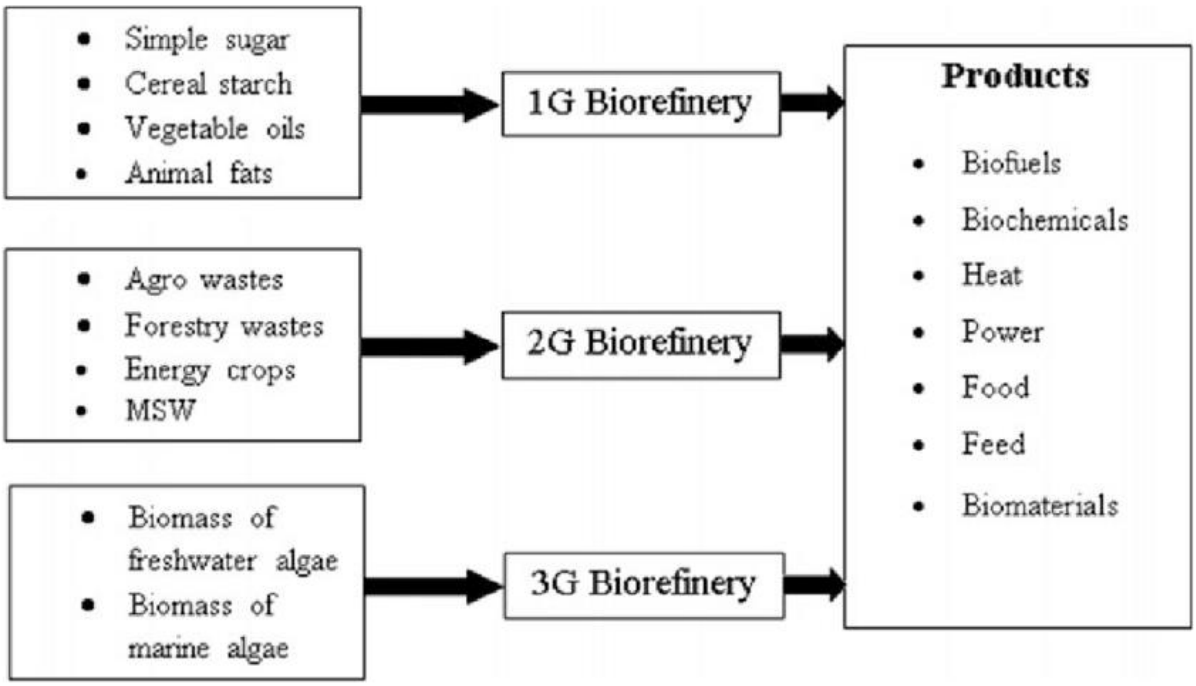
– First generation: Utilizing biomass from energy crops, primarily for the production of various oils, which are further processed and adapted for use.

– Second generation: Using non-food plant species, forest waste, and broadlyunderstood lignocellulosic biomass, often generated as by-products from previousproduction stages.

– Third generation: These are the most advanced biorefineries, utilizing biomass from living aquatic organisms such as algae. They represent the most advanced types of biorefineries among the aforementioned categories. The processing of biomass material yields not only energy products, but also valuable substrates for further use insectors such as pharmaceuticals, food production, or supplementation (Rathore 2016: 4).

It is the third generation biorefineries that address most of the challenges faced by engineers and chemical technicians, in terms of ensuring efficiency in sustainable energy production. These challenges included competition between biomass plants and food crops, high water consumption, the need for extensive cultivation areas, and the efficiency of bioconversion processes, which is highest with algae.

Scheme 4. Characteristics of each generation of biorefinery



Source: Chowdhury et al. 2018: 5.

It is obvious that small-scale production facilities or small farms are not able to obtain the financial resources needed to build a biorefinery and upgrade their entire energy system. However, a closed-loop economy can be a significant factor in the development of a network of cooperation between facilities with different characteristics and needs. In this way, the cooperation of local farms combined with a circular economy allows to meet the regulations on short supply chains.

Speaking of the entire bioeconomy, which includes technological, social, economic and ecological aspects (Kamble et al., 2020), it is essential not to forget one of the most important aspects, which are supply chains. On the one hand, they must be reliable and ensure continuity, and on the other hand, they must be fair and distributed in a way that benefits all entities involved in this model of cooperation. Modeling the profitability of installations such as biorefineries requires a wide range of information. Starting from biomass sourcing (Geographic Information Systems or computer modeling of cultivation) through logistics of the transport chain, to the creation of evolutionary algorithms that can integrate all the data and present the mostefficient solutions through analysis (Schröder et al., 2019: 7-9). In the current times of rapid implementation of Industry 4.0, the possibilities of modeling, instrumental analysis, and economic analysis canbe supported by systems and programs based on artificial intelligence. Ranging from the modeling of irrigation systems and the analysis of weather forecasting to the assessment of profitability for various methods, solutions, or technological modifications. The cognitive nature of the entire bioeconomy is unquestionable. It combines factors from the fields of economics, social sciences, energy, biotechnology, chemistry, and genetic engineering, necessitating a holistic approach to the planning and implementation of such systems. In orderto streamline the entire process and provide it with the greatest chances of success, eliminating the risk of design errors, society and authorities face the complex task of combining the knowledge of specialists from different, often distant fields, supporting investors and using the latest technologies such as machine learning and the Internet ofThings. This is a particularly important aspect, the intermediate goal of which is to facilitate the integration and cooperation of various economic centres.

Currently, most closed-loop biorefineries are built on a pilot scale. Due to the financial outlays required to build such installations and integrate the entire supply network, the time needed to construct and launch such projects is considerable. However, there are already several full-scale biorefineries operating around the world. A perfect example example is the BioRen facility, funded by EU funds, which is a project led by the company RenaSci (Plata et al., 2023: 10).

Anyhow, accelerating the process of implementing biorefinery technologies is a key factor in fulfilling climate objectives and achieving a rapid and smooth transition to a new model of theglobal economy. The processes occurring in biorefineries are already supported by technologies such as neural networks, machine learning, and artificial intelligence, primarily for:

– Analyzing the characteristics of the biomass used to determine the best process conditions (Nag et al., 2021: 3,5).

– Predicting the performance of specific technological processes, especially enzymatic treatments or hydrolytic pre-treatments (Vani et al., 2015: 2).

– Modeling the kinetics of processes occurring in bioreactors and determining theinfluence of physicochemical factors (Gama et al., 2017).

– Predicting the energy efficiency of products obtained in processes (Meena et al., 2021: 1-4).

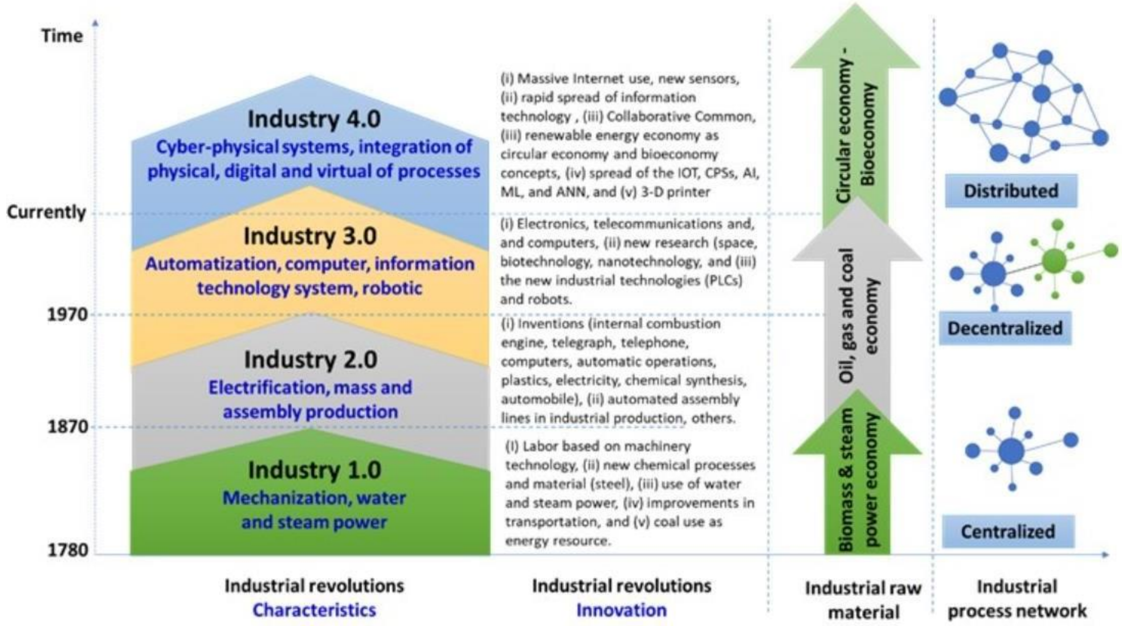
– Designing and analyzing online wastewater treatment and valuable biomass recovery (Kamali et al., 2021: 2,6,8).

– Assisting in climate, geographical, and weather analysis to determine the optimallocation for biorefinery construction (Sahoo et al., 2016).

– Designing and optimizing supply chains for biomass materials, waste collection, and process logistics (Liao et al., 2021: 5,7-8).

– Analyzing economic factors such as NPV, ROI, PBP, and LCA, as well as conducting more comprehensive and extensive analyses such as MCDA or SLCA (Ubando et al., 2020: 2) (Rakotovao et al., 2018: 2,5).

Scheme 5. Characteristics of technological revolutions



Source: Clauser et al., 2022: 2.

The development of biorefineries is an inevitable action for global economies, especially atthe local level. Energy, medicine, agriculture, and many other industries can collaborate in overlapping models. Modernization and transition to an economy entirely based on new economic trends is certainly a costly and long-term effort. It requires the development of logistics, transport, and simultaneous energy transformation. Social issues should not be forgotten either, including education of societies and training personnel who will play a significant role in modern technologies (Priefer, 2017: 6,10,15).

Conlusions

Energy has become one of the most important social topics worldwide in recent years. The path that the entire world has taken towards zero emissions is a long-term goal that requires the development of new ideas and technologies. Undoubtedly, the usage of algae in modern energy technologies is a developmental issue, and this trend should be closely monitored. However, society still has a long way to go. New economic pathways, based on the broad concept of bioeconomy, circular economy, or blue economy, will undoubtedly be partly basedon renewable biomass such as algae. However, apart from the advantages that come with the use of new technologies for development, there are significant challenges ahead. The global implementation of these economic models poses a range of social and technological challenges. There is a need for coordination among various sectors, including local communities, the public sector, and the private sector. As always, the entire process of transformation should be based on educating society, training new professionals, and establishing a position in the international market. Investment in research and development is also necessary to improve biorefinery technologies, logistical systems, and supply chain management models. Additionally, it is important to optimize work processes and analyses, which can largely be delegated to new technologies like AI or machine learning algorithms. The implementation of AI technology into bioeconomy and the broader industry of Industry 4.0 creates prospects for development and innovation. However, there are also challenges, such as the need to ensure adequate cybersecurity measures, data protection, and ethical useof artificial intelligence.

Society is only at the beginning of the journey towards complete 4.0 transformation. However, current scientific and technological advancements allow for an optimistic outlookon the future utilization of algorithms in economics and the circular economy. The path to fullimplementation may not be easy and will be filled with obstacles. Nevertheless, a well- thought-out bioeconomic model will lead to continuous economic growth while respecting theenvironment and addressing climate responsibility.

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