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Contact to corresponding author: Adam P. Balcerzak, a.balcerzak@uwm.edu.pl

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Adam P. Balcerzak
Brno University of Technology, Czechia
Centre for Business Research, Pan-European University, Czechia
orcid.org/0000-0003-0352-1373

Gazi Salah Uddin
Linköping University, Sweden
orcid.org/0000-0002-5744-0192

Bartosz Igliński
Nicolaus Copernicus University in Toruń, Poland
orcid.org/0000-0002-2976-6371

Michał Bernard Pietrzak
Gdansk University of Technology, Poland
orcid.org/0000-0002-9263-4478

Global energy transition: From the main determinants to economic challenges

Dynamic global energy transition has been accelerating for the last decade. Interestingly, the energy transition is multidimensional and concerns both the dimensions of technique/ technology and the economic, social, institutional, and legal spheres (Shuguang *et al*., 2022; Tzeremes *et al*., 2022; Ramzan *et al*., 2022; Tzeremes *et al*., 2022). The literature also points to the significant impact of the digitization of the global economy on accelerating energy transition processes (Shahbaz *et al*., 2022; Yi *et al*., 2022). It can be ex-

pected that due to the currently observed "Artificial Intelligence Revolution," this factor may gain even higher importance.

From the normative perspective, it is commonly assumed that the energy transition should proceed according to the idea of the energy trilemma, which emphasizes three key aspects: ensuring energy security, fair access to energy, and environmental sustainability (Liu *et al*., 2022). However, reaching this objective is one of the biggest challenges for highly developed societies; specifically, supporting this process is the greatest challenge for current science.

Energy security is about securing stable energy consumption for each economy while reducing the use of dirty energy and systematically expanding the resources of the renewable energy mix (Amigues *et al*., 2015; Nasir *et al*., 2022; Taghizadeh-Hesary *et al*., 2022; Ainou *et al*., 2023; Farid *et al*., 2023). Fair access to energy at the microeconomic level is associated with the risk of energy poverty in households, which may significantly limit their functioning (Davidson *et al*., 2021; Batool *et al*., 2022; Fraser *et al*., 2023). From the macroeconomic perspective, energy security is related to the principal of building high-security national energy system, which must be characterised with maximum resilience to geopolitical treats (Jonek-Kowalska, 2022).

In turn, the idea of environmental sustainability is not only related to eliminating the negative impact of energy transition processes on the environment, but also to obtaining positive effects of the transition, both in environmental and socio-economic aspects, defined as part of the implementation of the sustainable development goals set by the United Nations (Tzeremes *et al*., 2022, Gao & Chen, 2023).

Therefore, the energy transition process which is understood in this way is crucial for all three basic dimensions of a sustainable economy (social, environmental, and economic dimensions) and for increasing economic resilience both at the micro and macroeconomic level as well (Skvarciany *et al*., 2021; Matuszewska-Pierzynka, 2021; Richterová *et al*., 2021; Stjepanovic *et al*., 2022; Kowalska & Bieniek, 2022; Dvorskey *et al*., 2023; Balcerzak *et al*., 2023).

It should be emphasized that the currently progressing energy transition process results from many socio-economic phenomena, which have gained importance for the last 30–40 years. During this period, a whole set of changes occurred that enabled and positively influenced the systematic development of energy transition processes. The key determinant here is

the processes of globalization, which have been developing systematically and dynamically since the end of the 20th century (Li *et al*., 2021; Ramzan *et al*., 2022; Ahmed *et al*., 2022). The increase in interdependence resulting from globalization has contributed to the dynamic development of markets and their significant unification in terms of functioning, interrelations, and institutional changes (Fałdziński *et al*., 2016; Boateng *et al*., 2022). In this context, the growing role of the financial market is often pointed out, whose instruments are used to finance the implementation of energy transition (Shuguang *et al*., 2022; Ramzan, *et al*., 2022; Al Mamun *et al*., 2022; Lee & Lee, 2022; Zheng *et al*., 2023).

Additionally, globalization processes have influenced the significant economic growth of world economies and increased their competitiveness and innovation. Significant social changes have occurred in most countries, influencing pro-environmental changes in consumption patterns (Cong Doanh *et al*., 2021), including energy consumption. All the phenomena mentioned above have influenced the course of energy transition (Tzeremes *et al*., 2022; Sun *et al*., 2022; Mujtaba *et al*., 2022; Adebayo *et al*., 2022; Liu & Feng, 2023).

On the other hand, the currently observed retreat from that period of vigorous globalization and the time of growing protectionism opens a new chapter for the energy transition process, with the growing role of energy interdependence and energy security. The sudden change we have observed for the last two years confirms that these processes are directly or indirectly related to the changes in modern economies, societies and, obviously, politics, and are, therefore, difficult to control.

However, despite this change in attitude to unrestricted globalization, the measurable impact of the development of the international financial markets and the involvement of transnational policy in shaping the energy transition processes is emphasized (Shuguang *et al*., 2022; Ramzan *et al*., 2022; Al Mamun *et al*., 2022; Lee & Lee, 2022). Some new financial instruments are constantly created as part of the functioning of financial markets. These processes tend to structure state policy; legal solutions and public finances should support investments in energy transition processes (Lindberg *et al*., 2019; Shuguang *et al*., 2022; Shahbaz *et al*., 2022; Mahmood *et al*., 2022; Liu & Feng, 2023; Lee *et al*., 2023). This is extremely important because, on the one hand, access to financial market instruments and, on the other hand, access to modern infrastructure seem to be a necessary condition for the energy transition processes and enable, in the long term, the

unwavering development of modern technologies and the implementation of sustainable development goals. Therefore, it seems necessary for individual countries or international organizations to establish long-term energy strategies. From this last perspective, the mentioned determinants of energy transition are institutionally strengthened by the cooperation of countries at the international level and the creation of international legislation. In this case, the newly created institutions and legislation should ensure the socially fair nature of energy transition processes and, as far as possible, a positive impact on implementing sustainable development goals.

From this last perspective, the plans of international institutions are ambitious and assume that in the coming decades, the energy transition processes will positively impact changes in most countries' energy policies. In the case of analyzing the course of energy transition, it is assumed that it should be consistent with the sustainable development goals set out in the 2030 Agenda for Sustainable Development (Brodny & Tutak, 2023). International organizations point out that the energy transition related to implementing the Sustainable Development Goals will involve enormous economic effort, problems with society acceptance, reconstruction of markets, legislation, and institutions associated with investment expenditure that has yet to be recorded. From the European perspective, the ambitious plans of the European Commission, carrying out an energy transition based mainly on renewable energy sources, are aimed to lead to a situation where, by the end of 2050, we will have a decarbonized energy system.

Thus, as already mentioned, these factors force the implementation of substantial investment programs at the level of individual enterprises, entire economies, and even more blocs of countries. Achieving the indicated goals will not be possible without the active involvement of public funds, which in turn may force the need to change the recently widely accepted consensus regarding the foundations of the economic role of government, required or acceptable economic intervention of the state in a general sense, as well as the principles of a well-conducted fiscal policy in details (Balcerzak *et al*., 2016; Balcerzak & Rogalska, 2016).

From the more technical market perspective, an essential aspect of the energy transition processes is the creation of the renewable energy sector and its dynamic and systematic development (Wang *et al*., 2021; Agyekum *et al*., 2021; Calvo & Valero, 2022). In the case of the renewable energy sector, the most significant expectations are related to environmental protec-

tion (Ibrahim *et al*., 2022), socio-economic development (Gyimah *et al*., 2022), and the implementation of sustainable development goals (Bei & Wang, 2023). The energy transition based mainly on using renewable energy sources allows for the reduction of pollutant emissions, which have contributed most to the degradation of the natural environment over recent decades (Shuguang *et al*., 2022). Currently, electricity production, as well as the entire energy sector, is primarily based on the use of fossil fuels, the combustion of which is believed to be responsible for most greenhouse gas emissions. Therefore, the need to improve the energy production process is emphasized, where energy transition, including renewable energy sources, is expected to significantly reduce greenhouse gas emissions and pollutants in the coming decades. Finally, it is believed that it should translate into an improvement in the condition of the natural environment (Olabi & Abdelkareem, 2022). Due to availability, the most important for the renewable energy sector are solar energy, wind energy, and biomass (Olabi & Abdelkareem, 2022; Chang *et al*, 2022; Chang *et al*., 2022; Amjith & Bavanish, 2022).

However, it is essential that the renewable energy sector cannot be based on one energy source. Each country's energy system should be built on an energy mix based on a portfolio of renewable energy from various sources (Yana *et al*., 2022l; Bashir *et al*., 2022). Additionally, the production of renewable energy to replace energy based on fossil fuels will require enormous challenges for societies in terms of technology, technical, infrastructure, and resilience of economies, which will, in turn, be associated with challenges related to legal regulations, sources of investment financing and social issues (Boot-Handford *et al*., 2014; Abbasi *et al*., 2022). There is still a technological problem of using the short-term oversupply of energy from renewable sources. The solution to this problem is undoubtedly the use of green hydrogen. The economically practical production of hydrogen from the oversupply of renewable energy and its storage, and then the conversion of hydrogen into energy, fuels, and valuable chemical compounds, is expected to become of the most significant importance in the energy transition processes shortly (Capurso *et al*., 2021; Boot-Handford *et al*., 2021; Lebrouhi *et al*., 2022; Hermesmann & Muller, 2022; Qureshi *et al*., 2022; Amin *et al*., 2022).

Within this context, the last, but not most minor issue to consider — critical after 24 February 2022 (Fiszeder & Małecka, 2022) — is the new role of nuclear energy, which can become the crucial factor in the actual decar-

bonization process of the economy, and at the same time it can determine the abilities of many countries to improve stability of the energy systems within the objective of building geopolitical energy security, and sufficient resilience of national economies (Jonek-Kowalska; 2022).

The interconnections between the challenges described above relating to fundamental technological, social, and systemic changes indicate the scale of dilemmas and economic problems faced by global society and the scientific community, where the characterized multidimensional issues must be treated as a critical research subject.

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