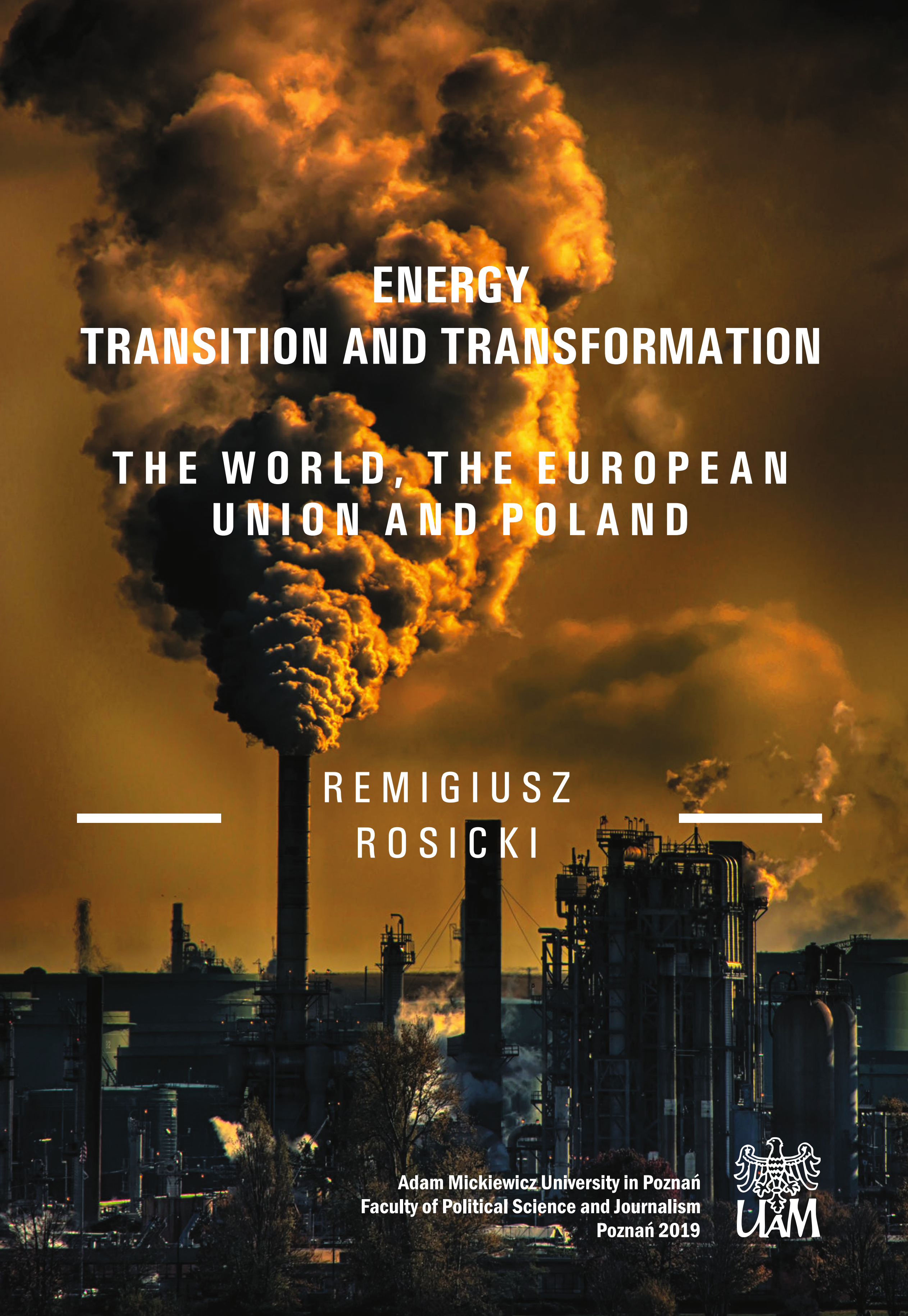

ENERGY TRANSITION AND TRANSFORMATION

THE WORLD, THE EUROPEAN UNION AND POLAND

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Poznań 2019

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Institutions:

CSO – *Central Statistical Office* (Polish Główny Urząd Statystyczny)
EIA – *Energy Information Administration* (USA)
EU – *European Union*
IAEA – *International Atomic Energy Agency*
IEA – *International Energy Agency*
OECD – *Organisation for Economic Co-operation and Development*
OPEC – *Organization of the Petroleum Exporting Countries*
TSP – *The Shift Project* (*Carbon Transition Think Tank*)
UN – *United Nations*

Units and energy:

EJ – *Exajoule* (= 1 *joule* × 10^{18}), 1EJ = 277,777,778 TWh
kV – *Kilovolt*
kWh – *kilowatt hour* (3,600 kJ; 3.6 MJ)
Mt – *Million tons*
Mtoe – *Million tonnes of oil equivalent* (11,630,000,000 kWh)
MW – *Megawatt*
PWh – *Petawatt hour*
toe – *tonne of oil equivalent* (~42 gigajoules; ~11,630 kilowatt hours)
TPES – *Total Primary Energy Supply*
TWh – *Terawatt hours*

Technologies:

CSS – *Carbon capture and storage* (*carbon capture and sequestration*)
GCR – *Gas-Cooled Reactor*
ICT – *Information and Communication Technologies*
IT – *Information Technology*
LWR – *Light Water Reactor*
PWR – *Pressurized Water Reactor*
PV – *Photovoltaic System* (*solar power system*)
RES – *Renewable Energy Sources*

Other:

ANT – *Actor-Network Theory*
CAS – *Complex Adaptive Systems*
CTA – *Constructive Technology Assessment*

DTA – *Discursive Technology Assessment*
EIS – *Energy Innovation Systems*
GPP – *General Purpose Principles*
GPT – *General Purpose Technology*
IAM – *Integrated Asset Modelling*
MLP – *Multi-Level Perspective*
pTA – *Participatory Technology Assessment*
PTA – *Parliamentary Technology Assessment*
R&D – *Research & Development*
SCOT – *Social Construction of Technology*
STS – *Science, Technology and Society Studies* (Science and Technology Studies; Science Studies)
TA – *Technology Assessment*
TIC – *Techno-Institutional Complex*
TIS – *Technological Innovation System*

Introduction

The main aim of this publication is to expose the reader to basic problems and directions of research into processes and changes in energy structures and technologies. The present work is primarily an overview with regard to a presentation of theoretical aspects of technology and energy paradigms as well as theoretical aspects of energy transitions and transformations. The reference materials that have been gathered and written up, and which concern the research problem have been supplemented with the author's own conclusions and evaluations. The theoretical issues have been supplemented with two case studies concerned with a transformation of coal paradigms. In the former case an analysis is performed of the transformation of coal paradigm in the world and member states of the European Union, while in the latter case the analysis focuses on the transformation of coal paradigm in Poland. In both cases a long historical perspective has been adopted so as to demonstrate the main points of energy substitution or a lack thereof.

The presentation of theoretical issues, which encompasses such categories as a "paradigm," a "transition" and a "transformation" is intended to demonstrate a logical sequence between T.S. Kuhn's concept of science, evolutionary economics, J.A. Schumpeter's innovation studies, innovation studies within the neo-Schumpeterian trend and variants of social study of technology.

The acceptance of a possibility of change of technology and energy paradigms results in referring to analyses addressing the issues concerned with energy transitions and transformations. It must be pointed out that in the source literature various terms are used to define processes and changes in the energy industry, e.g. a transition, a transformation and a revolution. Sometimes use of a specific term is made because of a methodological and theoretical position taken or because of ideological inclinations; at other times a choice of a given term is made for instrumental reasons. An intentional distinction of kinds of processes and changes can be exemplified with the typology put forward by F.G. Geels and J. Schot. It considers a reproduction, a technological substitution, a transformation, a reconfiguration and a shift with a return to stability. In a narrow sense, processes and changes in the energy industry usually come down to the issues concerned with the substitution of carriers or energy technologies, while broader approaches allow for a role of a great many factors in the processes and changes, e.g. cultural, social, institutional and political ones; also, a variety of effects of substitutions is pointed to.

It is well-nigh impossible to present in the introduction all the researchers whose works have contributed to the study of processes and changes in energy structures and technologies. One part of this work makes a synthesis of the main research directions. For this purpose, use is made of earlier research papers, which have been supplemented with the author's own conclusions. Still, it is worth naming such figures as R. Fouquet, A. Grübler, C. Marchetti, N. Nakićenović, P.J.G. Pearson, V. Smil and B.K. Sovacool. With regard to the contribution to the synthesis of the studies of processes and changes in the energy industry, it is worth mentioning the following texts: *Energy transitions research: Insights and cautionary tales* by A. Grübler, *How long will it take? Conceptualizing the temporal dynamics of energy transitions* by B.K. Sovacool, and *Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework* by A. Cherp, V. Vinichenko, J. Jewell, E. Brutschin, B.K. Sovacool. As for the significance of quantitative research with regard to turning points and pace of energy substitutions, it is worth mentioning a joint publication by N. Nakićenović and C. Marchetti entitled *The Dynamics of Energy Systems and the Logistic Substitution Model*, and another joint publication by N. Nakićenović and A. Grübler entitled *The Dynamic Evolution of Methane Technologies*. With regard to the contribution to the analyses considering further-reaching historical perspectives, and with regard to in-depth research into the services of end-use of lighting, transport and energy supply, it is worth mentioning texts by R. Fouquet and P.J.G. Pearson, e.g. *Five Centuries of Energy Prices* and *Seven Centuries of Energy Services: The Price and Use of Light in the United Kingdom (1300–2000)*. With regard to the contribution to the synthetic approach to energy structure transformations in Europe in a further-reaching historical perspective, it is worth mentioning a publication edited by A. Kander, P. Malanima and P. Warde entitled *Power to the People: Energy in Europe over the Last Five Centuries*. Last but not least, it is worth mentioning V. Smil, whose works are most comprehensive and include synthetic approaches to changes in energy structures in longer time-frames and analyses of turning points and pace of energy substitutions. V. Smil is also an author of many publications which aim to introduce the reader to the subject of energy and energy technologies.

Chapter 1

Theoretical aspects of technology and energy paradigms

1.1. The concept of paradigm

The concept of *paradigm* was introduced into science by T.S. Kuhn, who presented its significance in the context of scientific revolutions. However, it must be borne in mind that the concept of *paradigm* (Greek *παράδειγμα*) was known in ancient philosophy. For instance, Plato considered *paradigm* to be a pattern used by a demiurge (Greek *δημιουργός*, *dēmiourgós*) while creating the world. In the Platonic scheme of things, a *paradigm* is an original term for ideas that are models on which objects in the material world are patterned. (Reale, 1997, pp. 88–112, 157–188; Kępa, 2015, pp. 361–362). A complementary conception of *paradigm* and mechanisms of its change were presented by T.S. Kuhn in his 1962 work entitled *The Structure of Scientific Revolutions*. It questioned former concepts of science development, that is a concept of extreme development by accumulation and dialectal development (Such, Szcześniak, 1999, pp. 95–108). The anti-cumulative concept put forth by T.S. Kuhn pointed out that the development of science is not based on continuity, but on a special kind of severance with regard to a lack of correspondence between *paradigms* that follow one another in succession, and so it must be assumed that the development of science necessitates scientific revolutions.

A *paradigm* is to be understood as a set of concepts, theories and research methods that constitute a given field of science. Overall assumptions contained in a *paradigm* enable further development of particular sciences. T.S. Kuhn himself terms *paradigms* “universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners” (Kuhn, 1996, p. X). Thus, *paradigms* are past achievements that have been accepted as foundations for scientific knowledge and practice by current scientists. A *paradigm* assumes a significance owing to its originality and attractiveness. These features affect the scientific milieu in a way that makes it follow a given model of scientific practice, that is laws, theories, applications, etc. Still, the effectiveness of *paradigms* as regards solving problems has a practical dimension, because if a function like this is missing, the result will be a slow or quick *paradigm* shift (Kuhn, 1996, pp. 10–51; Bird, 2000, pp. 65–96).

A *paradigm* shift takes place whenever a scientific milieu becomes confirmed in their belief that the new and emergent explicative challenges can no longer be met on the grounds of the available knowledge and old methods. Emergence of a greater number of anomalies, that is situations that contradict the premises of the *paradigms* increases cognitive dissonance. Conversely, looking for better solutions gives rise to a consolidation of more groups as part of a new research program; at the same time dispute grows between supporters of concurrent *paradigms*, which in turn results in a phenomenon of a disappearance of their correspondence (Kuhn, 1996, pp. 52–76).

Consolidation of a new *paradigm*, as the so-called normal science is nothing other than a scientific revolution done. The concept of a scientific revolution is T.S. Kuhn's deliberate analogy with political processes. A significant point in the processes of an emergent political revolution is a conviction that the existing institutions are ineffective in solving social problems, just like in the case of an emergent scientific revolution where the scientific milieu becomes convinced of the ineffectiveness of a given model of scientific practices. Thus, a choice between competitive *paradigms* is like a choice between competitive political institutions or different lifestyles. The groups that will refer to the old *paradigm* will in fact engage in a scientific isolation, but the price to be paid for scientific advancement is a risk of error which is connected with being involved with the receding *paradigms*. At the same time, it is worth quoting T.S. Kuhn as stating that a new paradigm does not need to come into conflict with any one of its predecessors, as it might concern issues as yet unknown, or it might consolidate some theories of a lower order (*Ibidem*, pp. 92–110).

Still, it is noteworthy that T.S. Kuhn's concept of *paradigm* displays similarities with discussion of various social and political orders which can be encountered in social sciences. For instance, the subject of a variety of social orders has been addressed in writing by K. Mannheim, S. Ossowski as well as P.L. Berger and T. Luckmann (Mannheim, 1952; Berger, Luckmann, 1967; Ossowski, 1967; Mannheim, 1974; Mannheim, 1979). By way of generalization of all the discussion engaged in by the above-mentioned authors, it should be pointed out that orders (and their particular variants, e.g. cultural, social, political and scientific orders) are characterized by giving rise to prevailing discourses and practices; they make for the necessity to espouse or reject their rules; they construct identities against others, while creating efficient tools of exclusion, which are then used against opponents or adversaries (Cf. Rosicki, 2014, pp. 35–52). Another presupposition would be to accept a statement whereby orders comprise some socially conditioned knowledge, often with regard to interests expressed by dominant groups or dominant members of groups (Cf. Miłkowski, 2011). Still, it is noteworthy that the greatest similarity of presuppositions contained in T.S. Kuhn's discussion can be demonstrated with works by L. Fleck and P. Duhem, which follows directly from the fact that the American scholar borrowed their scientific views (Fleck, 1986 [1935], pp. 59–78; Fleck, 1986 [1936], pp. 79–112; Fleck, 1986 [1946], pp. 113–127; Fleck, 1986; Duhem, 1996; Jarnicki, 2010, pp. 64–78; Szlachcic, 2010, pp. 223–249; Afeltowicz, 2012, pp. 41–71; Wegmarshaus, 2013, pp. 40–51).

In order to describe the significance of research communities, L. Fleck used the term of a style of thinking (*Denkstil*) and a community of thinking (*Denkkollektiv*). The former should be associated with selective and appropriately directed activities by community members, which results in an emergence of a collective image of reality and thought compulsion. On account of the consolidation of the normative-epistemological system effected by the research community, its cohesion too becomes consolidated, the result being a low level of tolerance for members of competitive communities. The latter term is to be associated with an isolated community which is an autopoietic system that accomplishes secondary socialization of each one of the members. The community is legitimized by its own peculiar thinking style which is a characteristic endogenous and exogenous filter. Still, it is noteworthy that given social development communities operate in various configurations and are not completely resilient to exogenous factors. L. Fleck writes that the thinking style – developed within the community – creates a reality in the same way in which cultural creations are made, and at the same time it undergoes harmonious changes, just like cultural creations do. The fact remains that their homogeneity sometimes stands in the way of knowledge innovativeness, because sudden changes in the system of beliefs involve a tremendous amount of effort that must be made in order for the change to be effected by the community itself (Fleck, 1986 [1935], pp. 59–78; Fleck, 1986 [1936], pp. 79–112; Fleck, 1986; Afeltowicz, 2012, pp. 47–68).

Out of the knowledge of the scientific paradigm its main features should be distilled, that is the fact that it constitutes a symbolic generalization, which is made up of formalized propositions concerned with scientific laws and categories. A paradigm is also made up of researchers' beliefs concerned with the ontological and epistemological aspects of their research process. Besides, paradigm characteristics should also include an acceptance of some kind of value system, as well as a scientific value system. In the former case, such a presupposition would mean that sciences are not free from value judgments, while in the latter case it would be necessary to posit that sciences have their own logic of the research process, which is based on a proper selection of propositions to be verified (Kuhn, 1996, pp. 85–98; Bird, 2000, pp. 65–96). However, there is no doubt that the paradigm performs an instrumental function inasmuch as it controls research work by modelling it and laying down the rules. The instrumentalism of the paradigm also lies in the fact that it can discriminate against other approaches, solutions and rule systems, whose legitimization it downgrades both in the scientific community and in a wider public.

1.2. The concept of technology and energy paradigm

A replicated pattern of a special kind of practices of energy production, consumption and transformation is to be recognized as an *energy paradigm*. A hegemonic essence and structure of an *energy paradigm* essentially contains all characteristics of instrumentalism, which have been ascribed to the *scientific paradigm*, and so it must be pointed out that: (1) it imposes a style of thinking about energy conversion processes, (2) presents an evaluation system for cost-effectiveness and rationality of particular solutions concerned with energy conversion, (3) discriminates against other energy approaches and solutions, (4) is a peculiar endogenous and exogenous filter as to the choice of crucial energy problems, energy technology innovations and inventions. In general, three planes of such a paradigm should be pointed to, along with a system of their mutual interaction.

A general approach to the planes of an *energy paradigm* should consider: (1) a social plane, (2) a cultural plane and (3) a technological plane. In the case of the social plane, social actors, that is particular social entities and groups should be taken into account. Reckoned among significant social actors should be political decision makers, business entity owners, company management, company employees, science and technology staff, social movement representatives, etc. As for the second plane, the factors to be considered include practices concerned with and the discourse about energy use, as well as the individual and group consciousness of energy users. Regarding the last of the above-enumerated planes, a distinction should be made between non-material and material aspects. The non-material aspects are concerned with, inter alia, technological and organizational knowledge, whereas the material aspects are concerned with a specific technology and infrastructure of energy companies (Cf. Rosen, 2002, pp. 1–27). This approach appears to be in keeping with the presuppositions featuring in the concepts of network analysis of social relations, where both human and non-human factors are distinguished (Cf. Leydesdorff, Ahrweiler, 2014, pp. 2359–2374).

In the analysis of energy and environmental issues, various concepts and terms are used to depict that which in the work was termed *energy paradigms*. For instance, G. Dosi uses the concept of a *technological paradigm*, which he understands as a pattern for solving selected technological and economic problems on the basis of specified rules, which is determined by knowledge, skills, innovation, etc. G. Dosi also draws on the concept of a *scientific paradigm*, which he employs for his own use in order to characterize the technological and economic spheres. In this approach, a *paradigm* is a set of various inventions that will undergo further development and improvement, but also a set of rules making it easy to choose that which we are to look for and develop, as well as the direction in which we are supposed to turn the changes in particular technologies (Dosi, 1988, pp. 221–238). In other words, *technological paradigms* define possibilities for further technological innovations and basic modes of their application. Owing to the fact that they are an endogenous and exogenous filter, they can channel the efforts at technology development in a desirable direction. A course of technological development is determined by technological progress and a resultant of technological and economic problems offered by the *paradigm* itself (Nelson, Winter, 1977, pp. 36–76; Dosi, 1988, pp. 224–225).

Innovation processes are crucial change factors within a technological *paradigm*. In some approaches innovation is recognized as the main development factor of particular technology sectors, which nevertheless is viewed as an endogenous factor in a given sector (Cf. Schumpeter, 1939, pp. 65–196). As for innovativeness, J.A. Schumpeter draws attention to a combination of factors of production; namely, apart from basic factors of production such as work, capital, land and – after Marshall – also organization, the Austrian economist emphasizes the significance of enterprise. According to J.A. Schumpeter, innovativeness can take place on a variety of levels, that is it can concern: (1) introduction of a new product or a product of novel quality, (2) introduction of a new production method as well as a new distribution form, (3) exploration of new market niches, (4) prospecting for new resources, (5) introduction of a new sector organization (Maślak, 2002, pp. 221–231). More often than not, economic approaches emphasize one of the features of innovativeness, that is gaining a competitive advantage, and by extension making greater profits. Yet, it must be stressed that being innovative alone does not translate into success in a given field of technological and economic activity. Hence, a whole combination of factors makes for the success of innovativeness; these should include cultural, social, organizational, institutional, structural and suchlike factors.

Also, of great significance is the scale of change, for instance in the Schumpeterian approach, change may take on a radical form (implementation of innovation on a large scale), or an incremental one (implementation of innovation on a small scale). Both of the above-mentioned kinds of innovation implementation affect structure transformations in individual sectors and markets (Schumpeter, 1939). It is noteworthy that production organization in itself does not need to be based on new scientific discoveries, because organizational changes may take place in a situation where already existing technologies which have become established in a different sector or sectors are being implemented. Apparently, in the case of an organizational strategy which consists in minimization of costs of inappropriate implementation, it is better to rely on incremental processes and changes. However, relying on improvements (incremental innovations) alone may lead to technological backwardness. Binding innovation closely with production results in every kind of process and innovative change being characterized by only its own peculiar features (Linton, 2002, pp. 65–79). This will also be observable in energy innovations, where implementation of energy technologies or substitution of energy carriers may have their own determinants and own dynamics. Such a position, right next to general studies of innovation, will open up subsequent fields of research concerned with comparative studies of various innovations, sectors, development trajectories, as well as of innovation factors, for instance, economic and social ones. Therefore, it is to J.A. Schumpeter's credit that he approached the issues of innovativeness within a more dynamic framework, and stressed the relevance of innovation itself for advancement and social progress. Noteworthily enough, J.A. Schumpeter does not eschew ethical judgments, notably radical innovations or creative destruction happening within broader processes of capitalist economy (Schumpeter, 1947, pp. 149–159; Drucker, 1985; Schumpeter, 1994, pp. 81–86; McCraw, 2007).

Ch. Freeman and C. Perez use the term of a "techno-economic paradigm," which allows for common technologies impacting the operation of companies and individual sectors within the whole economic system. In this approach a *paradigm* is a macroeconomic concept, and may also refer to national innovation systems, as well as it can be considered from the perspective of the so-called long duration (French *longue durée*) (Freeman, Perez, 1988, pp. 38–65; Freeman, 1995, pp. 5–24). Ch. Freeman himself also invokes the Kuhnian *paradigm* as an analogy with the working of the technological *paradigm*. The author ponders the character of the changes and shifts between individual technologies, technological systems and *paradigms* – is it natural or are they determined by social and institutional factors? (Freeman, 1994, pp. 463–492). Undoubtedly, a premise to be accepted as the proper one is that such technological factors as co-evolutionary, organizational, sectoral, social and institutional ones may exert considerable influence on transitions between technological *paradigms*, but they may also lead to blocking the dynamics of technological advancement, and result in becoming dependent on the pervasive technology (Cf. Klein, 1977; Bijker, Law, 1992; Freeman, 1994, pp. 482–488). In the case of a negative trajectory, that is technological dependence on the pervasive technology, the presuppositions that were made earlier with regard to the exemplification of *energy paradigms* must be adopted.

It is to be noted that the concepts of technology and innovation diffusion that stress individual companies, processes and technologies are valuable, and yet they may be insufficient for comprehensive understanding of this kind of processes. Adopting a broader time-frame and a more elaborate network of interrelations in the research perspective would seem a more effective approach to the issues of technology diffusion. In the analysis of the issues concerned with energy, electricity, transport, etc. account should be taken of broader connections between concurrent technological, organizational and social innovations. A perspective of long-term economic cycles, which underlies the concept of Kondratiev waves, may serve as an example of such an analysis.

Identification of changes in long-term cycles makes sense if they are sudden and involve wide-ranging consequences. According to Ch. Freeman and C. Perez these traits justify use of such terms as a "technological revolution," a "techno-economic paradigm shift," and a "technological regime change" to describe this kind of changes. Intensity of changes enables a presentation of a typology of innovations and their diffusion, which would take into account quantitative and qualitative changes. Ch. Freeman and C. Perez distinguished the following types of innovation and diffusion: (1) gradual innovation, (2) radical innovation, (3) new technological systems, (4) techno-economic paradigm shifts (Freeman, Perez, 1988, pp. 45–47; Freeman, 1991, pp. 211–229). One cannot but notice that the proposal for an innovation typology presented by the author is identical with a variety of interpretations and theories of development of science and knowledge themselves (Cf. Elias, 1972, pp. 117–133; Such, Szcześniak, 1999, pp. 95–108; Lebedev, 2014, pp. 201–207).

The first of the types, referred to as gradual innovation, is characterized by a process of permanent changes of varying quantitative intensity and in different sectors, but the changes only concern improvements to inventions, processes, production organization and systems. Even though each one of these changes is of considerable significance, taking all of them into account does not mean structural changes to the economy. Their significance is shaped by the supply relationship, which should be associated with adoption and acceptance of new technologies and innovations by consumers (Freeman, 1991, pp. 222–223).

The next type, radical innovation, was the main focus of the studies of technology and innovation propagation. In these approaches the process of innovation introduction was often characterized with the aid of a sigmoid curve or a product lifecycle, which presented gradual improvements to the incumbent technology, processes and systems. The essential thing about this approach is the fact that radical innovation is possible in a situation where technological changes take place simultaneously with organizational ones, but in the absence of sufficient and favorable institutional conditions (*Ibidem*, 1991, p. 223).

The third type is a new technological system including constellations of economic and technological connections. Such systems can be illustrated with the clusters of innovation in the petrochemicals and plastics industry that developed between the 1930s and 1950s (Freeman, Perez, 1988, pp. 45–47; Freeman, 1991, p. 223). Household electronics clusters of innovation can serve here as another example, whereas the 21st century has brought innovation clusters in the area of energy technology (i.e. nuclear, low-emission, RES and energy-efficient ones). A broader perspective on economic, technological and organizational interdependence is capable of capturing conditions necessary for a reception of innovation along with the passage of time. For instance, reducing production costs of PV energy technology may be one of the factors dynamizing popularization of this kind of technology among individual consumers. Another factor determining the spread of PV technology would be a consumer loan support system making it possible for the public to purchase it at affordable prices. Thus, with a new technological system – in this case an energy one – becoming established, an approach taking into account a macrosystemic, mesosystemic and microsystemic analysis of the economy is necessary.

The last one of the enumerated types of innovations and their diffusion is the one of changes in the techno-economic paradigm. The name of the paradigm refers to two spheres, that is technology and economy, which is supposed to point to a wide range of changes and their interinfluence. A paradigm shift results in a spread of both radical, gradual and incremental innovations. These changes may not only concern adaptations of particular innovations, but also involve a development of whole new technology systems. For Ch. Freeman steam and electricity adaptations are an example of profound transformations of this kind. As for the economy, changes will involve emergence of new products, production methods, services and business lines. In order to characterize this kind of change, G. Freeman referred to the concept of a "creative destruction" ("a process of creative destruction," "a gale of creative destruction") by J.A. Schumpeter (Freeman, 1991, pp. 223–225).

J.A. Schumpeter himself, in order to illustrate creative destruction invokes such historical examples as rationalization of agricultural production, rationalization of the metallurgical industry, new methods of energy generation and new organizations of markets. All revolutionary changes come in waves, intervening between periods of relative calm, thus making for peculiar cycles. Appearance of a new cycle can be associated with what Ch. Freeman termed a techno-economic paradigm. These processes are permanent and progress from a revolution, through adaptations and diffusions of innovations. J.A. Schumpeter connected these processes with the essence of the capitalist economy and the working of economic entities which operate under capitalist economy. An analysis of these changes should be performed over long periods of time, i.e. over decades and centuries. While describing creative destruction, J.A. Schumpeter presented an interesting proposition whereby such processes and changes should be analyzed within the context of how the capitalist economy creates new structures, and then why it destroys them. For J.A. Schumpeter one of the mechanisms of the dynamics of change in the economy is not price competition, but competition based on new goods, technologies and organizational types as well as new supply sources (Schumpeter, 1994, pp. 81–86; Aghion, Howitt, 1992, pp. 323–351). Economic entities should be ready to destroy the economic foundation of their success. Therefore, one might say that the mechanism consists in making a pre-emptive move so as to secure for oneself an advantage and profitability in the future. Being insecure about the moves made by competitors is a factor incentivizing to look for new solutions (Cf. Mohr, Sengupta, Slater, 2010, pp. 9–37; 81–97). The energy industry offers an example concerned with traditional energy companies (e.g. coal, oil, gas) entering renewable energy sectors, and various finance companies withdrawing financial support for traditional energy companies or their investment in traditional energy generation.

Ch. Freeman and C. Perez borrowed the general assumptions underlying the mechanisms of the operation of the techno-economic paradigm from T.S. Kuhn's concept, which is what other representatives of the neo-Schumpeterian trend have also been doing. (Freeman, 1994, p. 487). Works by C. Perez on this issue (written along with Ch. Freeman or on his own) had quite an impact on the views of Ch. Freeman himself (Cf. Perez, 1985, pp. 441–463; Perez, 1989, pp. 1–37). The researchers presuppose that the techno-economic paradigm develops parallel to the old structures. The technology it introduces becomes the prevailing one in the long process of development and competition with other solutions. In order to become the prevailing one, a given paradigm must demonstrate that it is profitable both potentially and in reality. A natural process is to demonstrate effectiveness in individual industries, so that later on it can acquire legitimacy to impact other industries. But complete success of a new paradigm is possible following a profound transformation of social, institutional and economic structures (Freeman, 1991, pp. 223–225).

Ch. Freeman and C. Perez point out that for changes or a new paradigm to come into effect there must be the so-called "key factor" encompassing a combination of a few characteristics including: (1) relatively low and falling costs of solutions or technologies, (2) unlimited access to solutions or technologies, (3) practical potential of solutions or technologies, which enables their adaptation in subsequent solutions and technologies throughout the whole economic system, (4) potential for reduction in costs of capital, labor and products and for their qualitative change. A combination of all these characteristics under specific circumstances, which under normal conditions were probably available, given favorable conditions, is a proper answer to an increased demand for solutions or technologies capable of breaking through closed technological paths (Perez, 1983, pp. 357–375; Perez, 1985, pp. 441–463; Muchie, 2011, p. 138).[1] A combination of such characteristics is likely to feature in every stage of innovation expansion within N. Kondratiev's waves, for example in the case of steam engines, rail transport and metallurgical industry, machinery industry and electrotechnology, petrochemical industry (For more details see: Grinin, Devezas, Korotayev, 2014). One might also ask whether it is possible that the new stage of expansion, not included by N. Kondratiev in his works, will be initiated by new energy technologies. Still, before a new techno-economic paradigm can affect economic growth, as C. Perez claims, there must be a process of adaptation of the socio-institutional framework, in line with the stages of the Schumpeterian cycle (Perez, 1985, pp. 441–463; Freeman, 1994, p. 487). As we shift the discussion to the energy industry ground, this means that for new low-emission energy technologies to become established, first and foremost the socio-institutional blockades imposed by old solutions must be overcome.

[1] C. Perez and Ch. Freeman also enumerate other conditions: (1) new efficiency concepts for production organization at companies, (2) new management and organization models at companies, new and good organizational practices (3) orientation towards low labor costs per unit, as well as orientation towards new skills of the workforce, (4) orientation towards innovation in favor of key factors, (5) new investment patterns in favor of key factors, (6) orientation towards production with a higher speed of growth with regard to products with key results, (7) optimization of redistribution between entrepreneurs of varying operation scales, (8) new patterns of investment locations, (9) reorganization of relations between business sectors, (10) new patterns of consumption of goods and services, new consumer behavior patterns (as cited in: Perez, 1985, pp. 441–463; Freeman, Perez, 1988, pp. 38–65).

1.3. General Purpose Technology

Another approach on the borderline of the issue of technology and the operation of certain technological regimes as well as socio-technological regimes is the so-called general purpose technology (GPT). A GPT research trend focuses on the analysis of technologies capable of permanently affecting economic growth on account of the universality of their use (Haas, et al., 2016, pp. 538–550). Their import follows from three characteristics, among which B. Jovanovic and P. Rousseau reckon omnipresence (technologies should cover as many sectors as possible), improvement scale (improvement should go hand in hand with a reduction in costs incurred by their users) and reproduction (these technologies should facilitate subsequent innovations and manufacturing of new products or processes).[2] Besides, complementarity between the sector of technology supply and the sector of technology consumers is to be an indicator of general technologies (Jovanovic, Rousseau, 2005, pp. 1181–1221). In the approaches by T.F. Bresnahan and M. Trajtenberg a GPT in the first place focused on the management of innovation processes between higher-order sectors and lower-order ones. It was demonstrated that the missing flow of information on technologies between GPT suppliers and user sectors prevents their effective use, the negative result being for instance an economic slowdown (Bresnahan, Trajtenberg, 1995, pp. 83–108). The discourse around GPT did not touch upon issues unfamiliar in other research programs, e.g. in techno-economic regimes and historical or contemporary studies of macro-innovations (Cf. Lipsey, Carlaw, Bekar, 2005, pp. 85–130; Crafts, 2011, pp. 153–168; Haas, et al., 2016, pp. 538–550).

Of great relevance to the synthesis of views concerned with GPT was a publication by R.G. Lipsey, K.I. Carlaw and C.T. Bekar entitled *Economic Transformations. General Purpose Technologies and Long-Term Economic Growth*. The work proceeds in two directions, the first being a description of a GPT, the second a justification of the growth in the significance of the West. It appears that these two directions of the presented analyses can be connected; some will

[2] B. Jovanovic and P. Rousseau point to other features concerned with the introduction of GPT: (1) The introduction of GPT is associated with a temporary slowdown in efficiency (this results from the fact that new technologies may not be user-friendly) (2) The introduction of GPT is associated with a bonus for skills and acquired knowledge (in time demand for the entities that have acquired skills and knowledge of technology will rise; in time their income will rise in comparison with the entities that have not acquired them, (3) The introduction of GPT is associated with greater market fluidity (cases of market entry, market leaving and mergers), (4) The introduction of GPT is associated with stock valuation drops (the drops are dependent on the manner of acquisition of information about the entry into the GPT market and on acquisition of this knowledge), (5) New and small economic entities should be more effective in their operation on the market with regard to the introduction of GPT (new companies will register a higher level of innovativeness in their use of GPT potential, which will be coupled with a rise in the value of new entities in relation to old economic entities), (6) A rising interest in solutions while introducing GPT is related to the rising interest rates or deterioration in balance of trade (as cited in: Jovanovic, Rousseau, 2005, pp. 1181–1221).

easily adopt the proposition whereby a GPT directly influences continued growth which has been observable since the Industrial Revolution, and is related to the dominance of the West. But the authors do not emphasize this presupposition too strongly, which may follow from the fact that not all technologies referred to while characterizing the Industrial Revolution are classified as a GPT. An example of a GPT would be a steam engine, but M. Mure and S. Andes, making use of, inter alia, publications by N. Crafts, conclude that this technology increased annual work efficiency by 0.34%, while IT – by 0.6% in the period between 1995 and 2005, and mechanization of work – by 0.36% between 1993 and 2007 (Crafts, 2003, pp. 1–22; Lipsey, Carlaw, Bekar, 2005; Muro, Andes, 2015). However, R.G. Lipsey and the co-authors claim that new GPTs do not need to involve "productivity bonuses." P.A. David was of a similar opinion when he wrote that a new technology of this order does not ensure growth in efficiency immediately after it has emerged (David, 1989). What is more, there may be a slowdown in the productivity growth, despite the fact that at the same time a technology is developing rapidly, which is termed a "productivity paradox." Processes like this can be observed nowadays, for instance in the computerization of the USA in the decades of 1970s and 80s, but also in the period of a widespread adoption of steam engines and electricity (David, 1989; Brynjolfsson, Hitt, 1996, pp. 541–558; Macdonald, Anderson, Kimbel, 2000, pp. 601–617; Crafts, 2002, pp. 2–16). Undoubtedly, it must be posited that learning or adopting new solutions is accompanied by various adaptive costs, and new technologies are introduced under varying social, political and economic conditions, which can considerably affect the course of diffusion.

B. Jovanovic and P. Rousseau believe that by the beginning of the 21st century the main two GPTs were electricity and IT. By juxtaposing the two periods in which these two GPTs developed, that is the period between 1894 and 1930 (electricity) and the period between 1971 and the beginning of the 21st century (IT), they were able to present the following conclusions: (1) a slowdown in efficiency is connected with the beginnings of these two periods, (2) adoption of electricity progressed much faster than the one of IT, (3) adoption as measured by a relative price drop was more favorable in the case of IT, (4) both GPTs impacted subsequent innovation processes, but IT prevails by a number of patents and trademarks, (5) both GPT cases entailed "creative destructions" and turbulence as measured by overcoming barriers to entry, market liquidity, takeovers and changes in stock market valuations (as cited in: Jovanovic, Rousseau, 2005, p. 1182). Comparing three technologies, that is ICT (in the USA in the period of 1974–2000), electricity (in the USA in the period of 1899–1929) and steam engines (in the UK in the period of 1780–1860), N. Crafts concludes that by the mid-1990s the influence of ICT on economic growth had been greater in the respective stage of the initial adoption than in the case of steam engines, and at least comparable to the one of electricity (Crafts, 2002, pp. 2–16; Crafts, 2004, pp. 338–351).

Apart from pointing to the relation between technology, efficiency and economic growth, deciding what actually can be classified as a GPT seems to be problematic. For instance, R.G. Lipsey and his colleagues recognized the following GPTs in the period between the mid-15th century and the 2000s: three-masted sailing ships, printing, steam engine, mechanization, railroad, electricity. This modern typology of GPTs may raise doubts, but the fact remains that these are technologies and techniques that had tremendous influence on advancement. As regards productivity, which is an indicator for GPT evaluations, despite the emphasis laid on energy by the representatives of research into energy transitions, of great significance were the changes in production methods themselves, that is the changes that involved the development of the factory system, mass production and production streamlining processes. The authors themselves point out that singling out these three changes as separate GPTs may be disputable, and so maybe they should be classified as one and cohesive GPT (Lipsey, Carlaw, Bekar, 2005, pp. 169–218). As we recognize the considerable significance of changes in methods of production in the modern period, it must also be concluded that changing over to the factory system would not have been possible without steam or electrical energy supply, or without such minor innovations as better lighting, which made lengthening of the working day possible.

To describe processes and changes, R.G. Lipsey and his colleagues also used additional categories. And so apart from general purpose technologies, they singled out a category of general purpose principles (GPP). They are science or technology principles characterized by many features. No single implemented technology is a carrier of a GPP. While a GPT introduces a set of instructions to any given product, process or an organizational form, a GPP is a certain kind of idea or concept which may only imply a specific solution, but it does not constitute a real or concrete instruction. The idea of mechanization of work, which is forever being incorporated into ever newer spheres of human work, can serve as a socio-economic example of a GPP. Another example would be knowledge of the capability of fire to process various kinds of matter. Each one of these principles of operation has been used to create new technologies, including general purpose technologies. Thus, a GPP is a concept used in many different technologies widely applied in the economy, while allowing for the impact of indirect or unintended effects (*Ibidem*, pp. 99–100). The effect of the spontaneous spread can clearly be seen in the case of electricity being put to use, which resulted in innumerable benefits for suppliers and consumers. Another energy-related example which can be connected with GPPs is knowledge of splitting nuclei of heavy elements, which could be used in manifold ways, even in a number of nuclear technologies employed in electricity generation.

In addition, R.G. Lipsey and his colleagues extend the terminology concerned with macro-innovations, introducing a division of radical innovations into ones that are functionally radical and ones that are technologically radical. An innovation itself is gradual if it evolves from an existing technology, whereas a radical innovation is one that has not evolved from an incumbent technology through improvements or modifications. Differentiation can also be made with regard to evolving technologies, which can be divided into technologies of a specific kind and technologies for special needs. Given a trajectory of specific-kind technologies, a radical innovation is the case when a new technology has arisen from a consolidation of many others, while given a trajectory of technologies for special needs, a radical innovation is the case when it can't have evolved from a technology that preceded it (*Ibidem*, p. 90). GPTs are often functionally radical, but they are not technologically radical. For instance, a metal-hulled steamship was a radical innovation, but it can't have evolved from its predecessors, that is wooden sailing ships. A different trajectory, however, was the one followed by one of the propelling mechanisms in the steamship, that is a steam engine, which had a long history of evolution (*Ibidem*, p. 96).

1.4. Multi-Level Perspective and social study of technology

A *Multi-Level Perspective* (MLP), which was presented by F.W. Geels, is the concept that links the theoretical aspects of "techno-economic paradigms" or "technological regimes" with the achievements of evolutionary economics. Apparently, in essence the concept does not markedly diverge from the above-presented discussion of innovation processes, the significance of technology and organization in socio-economic processes as well as of barriers and facilities in the dynamics of these processes. In this approach one can see a departure from the narrative based on the language of economics and technique and an embrace of the narrative based on constructivist language. The multi-level quality, which is a prominent characteristic of an MLP, would earlier feature in analyses of economic and technological transformations on the grounds of systemic approaches or post-Schumpeterian economics. The analysis of various levels and aspects was approached from both one-dimensional and multi-dimensional perspective, which was typically determined by the willingness to appropriately explore the economic and/or technological problem; or it resulted from an interest taken in individual issues by different scientists, for the problem of technological transformation will be viewed differently by a macroeconomist, a microeconomist, or an economist specializing in a sectoral policy (Cf. Bain, 1959; Neuberger, Duffy, 1976; Porter, 1981, pp. 609–620; Porter, 1983, pp. 172–180; Reid, 1987; Tirole, 1994; Gorynia, 1995, Nelson 1998, pp. 319–333).

After F.W. Geels had redefined the underlying assumptions of an MLP, his approach changed in character, shifting away from the hierarchical multi-level structures towards a more flattened approach without a dogmatic, ontological status. This happened in keeping with the presupposition that there was no need to generate more planes of social activity, but it was expedient to point to spots where social interaction emerges. This might be the reason for the development of analyses which to a greater degree highlight basic ANT ideas. Still, F.W. Geels ascribed a fundamental meaning to the socio-technological regime as a "meso-level." The justification for that is the fact that the essence of an MLP should be constituted by research into transformations and shifts of socio-technological regimes, but also the adoption of the narrative whereby the other two levels are characterized with reference to this one (Geels, 2011, pp. 24–40). It is difficult to pinpoint what was the real and more significant cause of the shift of stance – was it willingness to break with the involuntary reference to systemic and functional approaches ("micro-meso-macro" approaches), or criticism of the lack of sufficient methodological sophistication? A criticism of this analytical approach chiefly concerns the ontological status of the accepted dimensions, epistemological issues, but among these accusations we might as well reckon problems concerned with: (1) a clear indication of determination factors, (2) defining directions of determination, (3) overdetermination of bottom-up innovation mechanisms, (4) a lack of a clear indication of mechanisms for innovations passing into main technological trajectories. Just concluding that there is a big number of factors of change, approached in a multi-dimensional and multi-level manner, which interact with each other and are subject to cumulative causality, does not absolve anyone of responsibility for distinguishing and demarcating them. There is no escaping the impression that this kind of fluid ontology and epistemology in an MLP performs an instrumental function which at the same time becomes a flawed argument in a debate with opponents of this approach, and not a mature methodological stance. Besides, adopting the presupposition of cumulative causality, and by extension – in the author's opinion – the hardly perceptible process of niche innovations penetrating into socio-technological regimes in connection with the so-called unique opportunities (*window of opportunity*, *critical window*) reduces methodology to a study of cases.

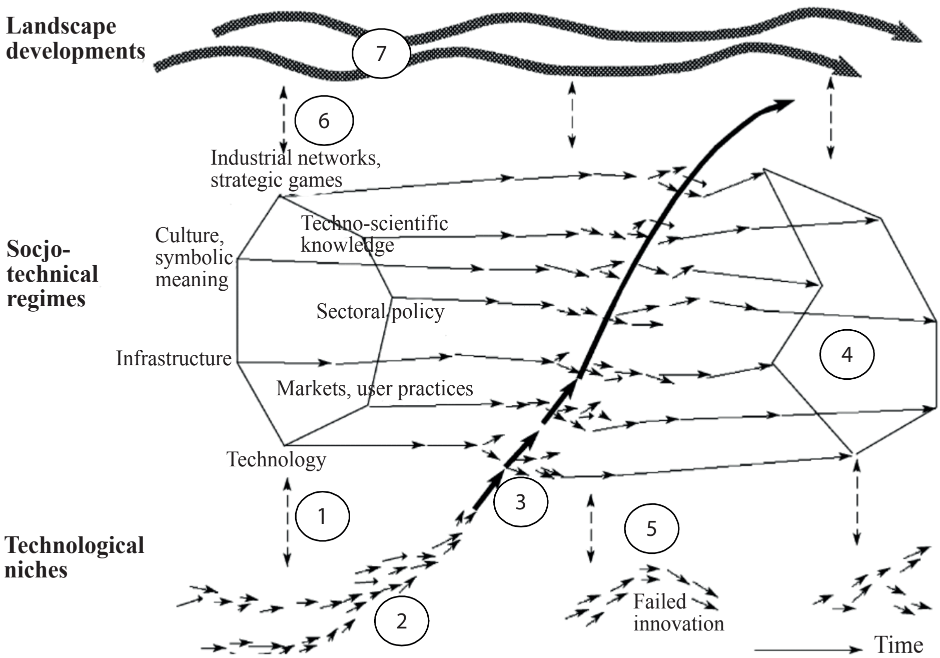
According to F.W. Geels a socio-technological regime is constituted by "deep structures" with established principles, practices, organizational cultures and technologies, all of which make up a stable whole. A. Smith, A. Stirling and F. Berkhout – following A. Rip and R. Kemp – accept that the socio-technological regime is about stable configurations of institutions, techniques and technologies, as well as rules, practices and links which determine development and use of technologies (Rip, Kemp, 1998, pp. 327–399; Smith, Stirling, Berkhout, 2005, pp. 1491–1510). In large measure this level constitutes one self-replicating mechanism oriented towards developing main technological trajectories. These are consolidated by gradual improvements through mechanisms of variability and selection, and it is the socio-technological regime that creates a selective filter for bottom-up innovations arising in niches. Selection of bottom-up innovations may be instrumental in resolving a conflict between individual regime parts, e.g. sub-regimes represented by certain industries – the energy sector, transport sector, military sector, etc. Selection may also consist in originating new trajectories, just as it may also give rise to a shift in the regime structure itself. New technologies often co-evolve alongside the functions which they provide and which are socially useful. Still, it must be borne in mind that changes to regimes are gradual and are aimed at optimization of effects; in cases of radical change the risk of the socio-technological regime becoming destabilized is too high. However, regimes themselves are inertial, which means that they are resistant to both internal and external interference, that is they are resilient to factors coming from the surroundings and their own structures. Thus, inertiality strengthens selected trajectories and directions of their development while improving them (Geels, 2011, pp. 24–40).

The concept of the niche was developed by American botanist J. Grinell at the beginning of the 20th century; as defined by him, the niche is a set of physiological and spatial factors essential for existence. According to S. Elton, a niche is a space containing all organisms with specifically ascribed functions in the ecosystem. While the former case points to spatial occurrence, the latter one stresses the significance of a place in the structure with regard to a function performed in the ecosystem (Cf. Tyus, 2012, pp. 263–274). With regard to specified conditions and account taken of the effect that various factors have in given space, various species compete with each other. One of the more popular principles concerned with co-occurrence of competitive species is the "Gause's law." It states that within the same area two competing species can only survive if they operate in two different niches, the result being a proposition that because of competition two similar species are unlikely to occupy the same niche. Discussion of ecological niches can have some relevance for the niches that act as technology innovation incubators. Therefore, niches within the MLP concept create conditions for emergence and development of radical innovations. These conditions may be of a various character; for instance, they can be institutional, infrastructural, economic, intellectual. Under these convenient conditions, or in such a safe environment, innovations are free of selection mechanisms that socio-technological regimes have at their disposal. Account should be taken of the fact that regimes can serve many niches where innovations arise, e.g. the military sector may in itself be quite a hermetic niche, but at the same time it can have strong institutional and financial support. At this point one might ask oneself whether this kind of niche, i.e. a niche connected with the military sector, is not in fact an innovation, as part of the socio-technological regime, and not a free innovation arising in niches?

The last one of the distinguished MLP levels is a landscape, which can be identified with a macro-level. The meaning F.W. Geels gives the landscape is the same as the one that F. Braudel gives the *longue durée* perspective. The stability and the broader perspective of the landscape are also testified to by the presupposition that on the micro- and meso-level the influence of various entities does not directly or immediately translate into what is happening in the surroundings. The landscape should be acknowledged as general socio-technological surroundings in which both immaterial and material aspects are vital. In the former case the factors that should be taken into consideration include values, awareness, the world-view, persuasions, while in the latter case – the institutions that this kind of immaterial aspects is connected with. The landscape is characterized by a higher level of stability compared with the other levels, as a result of which changes to it are slower (e.g. a shift in conservation awareness). F.W. Geels recognizes global structures of trade in natural resources, economic development, demographic processes, political processes, wars as falling within the general socio-technological surroundings (Geels, 2011, pp. 24–40).

While analyzing the landscape, F.W. Geels presents a mechanism of socio-technological transition. According to his assumptions, each kind of transition is of a special character on account of the fact that various configurations of factors appear on various levels; however, at least two mechanisms of influence can be pointed out. The first one is internal dynamics that is imparted by innovations emerging in niches; the other one is a shift within the landscape that exerts pressure on the regime. The result of their influence can be destabilization of the socio-technological regime, which can thus give rise to implementation of niche innovations (See Figure 1) (*Ibidem*, pp. 24–40).

Figure 1. The multi-level perspective on transitions



① – pressure exerted by niches on the regime, ② – a variety of early innovations, ③ – selection and implementation of niche innovations in the mainstream, ④ – a change in the regime structure effected by the implemented innovations, ⑤ – selection of innovations, ⑥ – pressure exerted on the landscape by the regime, ⑦ – evolution of the landscape.

Source: Geels, 2002, p. 1263.

It is noteworthy that one of the sources of an MLP as a research perspective proposed by F.W. Geels is, inter alia, evolutionary economics of the neo-Schumpeterian trend. Hence, the issues concerned with both technological regimes and with a technological transition constitute a mutually interrelated whole. F.W. Geels has a broad understanding of a technological transition in the sense that it encompasses a configuration of social functions, e.g. transport, communication and lifestyle. This can be exemplified with the road taken by information technology – from punched cards to digital computers (Geels, Schot, 2007, pp. 399–417).

A. Smith, A. Stirling and F. Berkhout, the latter of whom F.W. Geels refers to in his analyses, understand a regime transition as exerting pressure on processes of technology selection, and as coordination of the use of resources according to selection pressure. The exerted pressure can be of a various character, e.g. an economic one (taxes and other financial regulations), a top-down one (they may come from the socio-technological landscape; they may assume the form of a new economic model, new consumption patterns and dynamic demographic processes), a bottom-up one (innovative technology incubators within niches). Two main factors determine the potential of change in socio-technological regimes, i.e. availability of resources and use of resources (Smith, Stirling, Berkhout, 2005, pp. 1491–1510; Geels, Schot, 2007, pp. 399–417).

On account of the criticism coming from various trends within the family of research into *Technology Assessment* (TA) and, more broadly, also STS, F.W. Geels entered into discussion and provided a series of explanations that were supposed to dispel the opponents' doubts. The criticism was most often concerned with theoretical sophistication with regard to the issues concerned with subjectivity, MLP structures and socio-technological processes. Older approaches to studies of technology, which extensively drew on the developed categories, within social sciences, pointed out a number of ambiguities, shortcomings and gaps of an MLP. All the trends drawing on constructivist epistemology and ontology emphasized the necessity to have an MLP more firmly embedded in these achievements; SCOT and ANT may serve here as examples. In the former case the necessity to consider the social formation of scientific knowledge and technology was pointed out. The SCOT trend, following the findings of P.L. Berger and T. Luckmann, assumes that just like any type of knowledge can be socially formed, so technology can be socially formed too. Hence, within studies of technology interest should be directed towards the social context within which this technology appears. This kind of research perspective is supposed to counterbalance influential approaches reckoned as technological determinism. Reception of the achievements concerned with ANT, that is the achievements of M. Callon, B. Latour, J. Law and A. Mol, with particular emphasis on the achievements of B. Latour, was a natural consequence of the adoption of the social context by SCOT (Cf. Sismondo, 2010, pp. 57–71, 81–91). Among the scientists belonging to the SCOT trend reckoned should be Dutch technology historian and sociologist W. Bijker and British sociologist

T. Pinch, as well as American technology historian T.P. Hughes. Their collaboration brought publications on social construction of technological systems, e.g. co-edited monograph entitled *The Social Construction of Technological Systems New Directions in the Sociology and History of Technology* (Bijker, Hughes, Pinch, 2012). Despite the new approach to the issues concerned with technology development, it is hard to find in the works presented by W. Bijker and T. Pinch an honest justification for using the perspective of social constructivism. More often than not, many approaches based on social constructivism will only go as far as to justify that they can be applied to studies of technology, but they do not meaningfully explain why such a research program is more effective. The risk here is connected with a kind of instrumentally applied terminological metaphors which can vividly present processes taking place within the sphere of technological innovations, but cannot furnish any effective explications.

In the 1980s W. Bijker and T. Pinch synthetically presented assumptions underlying SCOT in a text entitled *The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other*. In it, the authors performed a short analysis of the studies of technology, comparing them with one of the programs of sociology of knowledge. It may be said that the conclusions following from the two trends of constructivist studies became a starting point for further development of the SCOT program. It is presumed within this trend that individual entities, and – more broadly – technologies, may be interpreted differently by individual social groups. For instance, interpretations may depend on social classes, social strata, occupational groups, sex, etc. Various perspectives on technology may affect directions of its improvements. It should be pointed out that SCOT considers quite a broad scope of social groups; in the first place, users and producers of technology should be recognized as essential groups. Groups which comprise neither users nor producers, but may substantially influence innovation processes are also taken into consideration; for instance, these include interest groups, representatives of social communication media. As we consider flexibility of interpretation depending on social groups, various directions of technology development should be embraced. Therefore, a potential multitude of interpretations means a potential multitude of trajectories of technology development. Various positions may lead to conflicts concerned with specific technological solutions, technological ideas, choices of technology, ethical aspects of technology and social effects of the implemented technology. Development and then consolidation of technology give rise to a certain kind of closure, which limits the discourse about it; it presumes that its presence and function are obvious. Still, it is noteworthy that the closure is not an irreversible process. It is to be assumed that the process that leads to suspension of discourse is the one of technology being widely tied to various social groups. A consensus which has arisen between the social groups results in a situation where interpretative flexibility of a given technology is slight (Pinch, Bijker, 1984, pp. 399–441; Bijker, 1995).

SCOT itself too came under criticism, which can be illustrated with the publication by L. Winner entitled *Upon Opening the Black Box and Finding It Empty: Social Constructivism and the Philosophy of Technology*. One might say that an MLP has taken over the use of metaphors characteristic of the trends within TA; anyway, it is to be discerned in many constructivist perspectives in the area of STS. That is why the criticism presented by L. Winner may be related to an MLP itself. According to L. Winner social constructivism opened a black box full of colorful tools, that is social actors, processes and their images, but the picture is not as colorful as one might expect; in fact, the author claims that the box is quite empty. It is true that social constructivism as part of TA was successful at explaining the course of technological trajectories and other attendant processes. However, according to L. Winner these findings do not go beyond establishing that some innovations are more vital than others, and that some succeed while others fail. These findings do not offer any meaningful judgment as to why that is the case, but more detailed, varied and understandable descriptions of technology development are presented. Hence, there are no generalizations which would be essentially significant when it comes to pointing to laws and rules, because the ones that are proposed in fact do not go beyond common knowledge of technology development and implementation (Winner, 1993, pp. 362–378). Some emphasize that shifting the focus from social studies of knowledge to social studies of technology was of an instrumental character in the scientific milieu, e.g. with regard to increased outlays on research concerned with social aspects of technology (Woolgar, 1991, pp. 20–50).

H. Collins and S. Yearly drew attention to threats to the effectiveness of the studies of technology within sociological studies of scientific knowledge, with regard to the adoption of the pervasive constructivist perspective. The authors write that each new perspective within the sociological studies of scientific knowledge followed the path of relativism, confirming scientists in their conviction that they were solving epistemological problems that earlier philosophers had not been able to deal with. The truth in science was supposed to be a "linguistic structure" and a "social structure," i.e. it was supposed to constitute some kind of social convention. Turning to the scientific practice as one of social life forms was recognized as a scientific method. But participation in one of social life forms can only be defined with the aid of a claim. Constructivism did not provide an answer to the question of how that claim could be justified; what's more, sociological studies of scientific knowledge may only be a mere element of the riddle of science that the studies claim to be solving (Collins, Yearly, 1992, pp. 301–327; Roth, 1994, pp. 95–108).

In ANT emphasis is laid on both human entities of influence and other objects such as mills, steam engines, water pumps, light bulbs, draught animals (actants, that is factors affecting other factors). With reference to earlier and established social theories, ANT posits an increased level of research sensitivity and clear-headed judgment, as well as more in-depth quest for relationships between human, material and immaterial entities (Cf. Nowak, 2015, pp. 65–79). B. Latour himself used the concept of a new kind of "empirical metaphysics" to the degree to which M. Wartenberg posited that every metaphysical thought construction should be more firmly embedded in experience, so that theoretical constructs would not be detached from reality, nor of an *a priori* character (Cf. Musioł, 2014, pp. 205–223). Just like P. Bourdieu's concept was supposed to be about some distance from previous social theories, not infrequently ones of a solipsist character, ANT comes in between dogmatic structures and fluid narratives. A.W. Nowak writes that ANT involves various benefits – on the one hand, this approach enables contextual analysis based on embodied micronarratives, while on the other hand, it enables verification of a manner of creating macro-actors and global influence (Nowak, 2015, pp. 70–71). Adopting the ANT perspectives may to some degree belittle the significance of L. Winner's criticism of some of TA.

Another trend that F.W. Geels refers to in discussion is *Constructive Technology Assessment* (CTA). The issues concerned with CTA were presented by J.W. Schot in his texts, and he was right to observe that in such trends as TA (including SCOT and CTA), ANT and neo-Schumpeterian economics (technological regimes and evolutionary approach to technology) the paths of scientific discourse about the technology issues converge (Cf. Schot, Rip, 1997, pp. 251–268). According to the author, the primary function of TA was cautionary, as it was to raise awareness as to what negative effects are involved with development of certain technologies. As the economy witnessed transformations, a political function too was ascribed to TA in the sense that it was supposed to constitute support for a public policy with regard to the choice of a strategic technology. In the case of the energy industry, TA would point to threats concerned with an introduction of a specific kind of energy generation or a selected energy technology, e.g. nuclear or renewable energy. Within the compass of the political function, TA would present scenarios for development of energy technology along with an evaluation of synergy with other sectors.

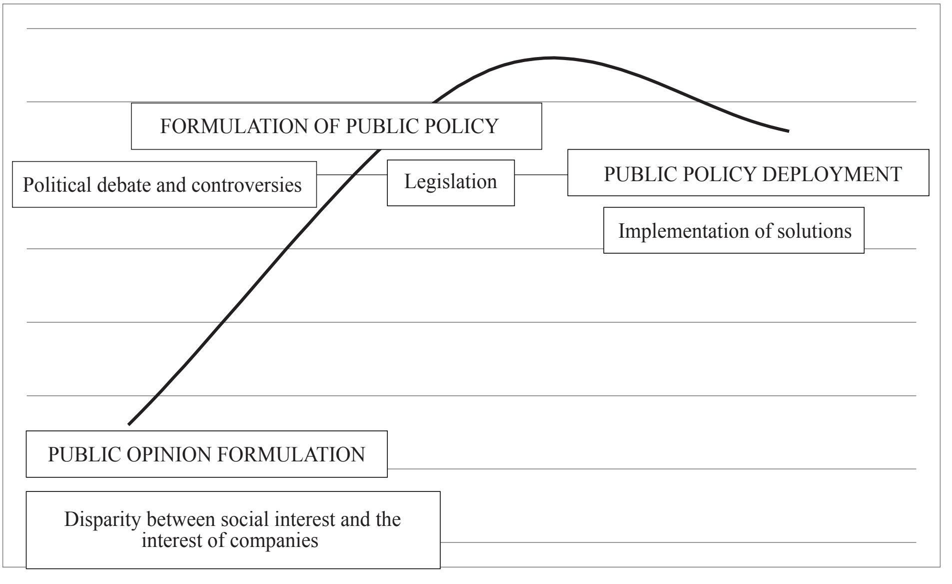
J.W. Schot emphasizes that the neo-Schumpeterian concept constitutes a starting point for the theory of technological development. Evolutionariness means that a technology can develop by trial and error, as well as by way of variation and selection processes. In a free market economy, it is the market itself that constitutes a selection mechanism, but – as J.W. Schot rightly observes – representatives of the neo-Schumpeterian trend are rather unlikely to use the market terminology, and prefer the "evolutionary" terminology, in this case – the term of environmental selection. Still, it must be noted that the selection encompasses not only the neo-classical concept of the market but also institutional and geographical factors (Nelson, Winter, 1977, pp. 37–74). Apart from the market, institutional and geographical factors, attention can be drawn to anticipation of future profits concerned with development of a given technology (Van den Belt, Rip, 2012, pp. 129–153). It follows that CTA is oriented towards the issues concerned with selection, because this mechanism would enable effective performance of the warning and politico-predictive function. But rather than on the influence exerted on political entities with regard to their political activity and decisions, CTA is more focused on social entities which consume technologies. Influencing social entities makes it possible to obtain feedback from typical users of technology; then the feedback can be utilized in the processes of technology design and implementation (Cf. Schot, Rip, 1997, pp. 251–268). And hence in CTA a vital role is played by activity affecting: (1) creating broad-based social discourse on individual technologies, (2) use of the involvement on the part of technology users, (3) formation of technology user awareness and competence. CTA was subject to constant development, which progressed from elaboration of support for technology towards: (1) a theoretical formula for scientific research into technology, (2) practices supporting decision-making processes in national, social and economic institutions, (4) practices concerned with technology design, (4) practices of communicating with technology users.

In their text entitled *Multi-dimensional struggles in the greening of industry: A dialectic issue lifecycle model and case study* C.C.R. Penna and F.W. Geels used an MLP to analyze the development of "green industry." The authors focused on a special kind of socio-technological regime, that is the industrial regime. The main relation pointed to with regard to the change in the regime is environmental pressure. The main two spheres affecting the industrial regime are: the institutional environment and the external environment, the latter of which influences achievement of goals adopted by companies. The external environment should include other companies, economic activity competitors, suppliers, consumers and the workforce available on the job market. This environment is important inasmuch as within it companies struggle with economic pressure. The main mechanisms of economic selection should comprise vying with competitors, the bargaining position of the suppliers, the bargaining position of the purchasers, new market players and alternative technologies. The institutional environment should include politicians, public opinion, social movements and other organizations soliciting support – the influence of all these elements makes for selection pressure within the environment. As part of the industrial regime one should also recognize trade entities that mediate in the relations with the external environment. The general assumptions underlying socio-technological regimes presupposed their cohesion, and in this case industrial regimes are characterized by relatively cohesive elements, that is (1) technical skills and knowledge that are of vital importance in economic and innovative activity, (2) identity and mission (society- and trade-related), (3) responsiveness to signals coming from the external environment, (4) legal regulations and an institutional policy that affect the operation of companies (Penna, Geels, 2012, pp. 999–1020).

If we reduce the issues concerned with the clean environment to lowering the greenhouse gas emissions down to the minimum, then through the prism of this issue we can perform an analysis of "green industry." The main pattern of processes within the Green Industrial Policy (GIP) is a cycle beginning at the activity of civil society, progressing through the following stages – exerting influence on politicians, adjusting the demands to political activity, and finally institutionalizing "green demands" as part of individual public policies (See Figure 2) (Cf. Buchholz, 1988). A traditional cycle of green policy formulation is based on analogous stages which can be seen in economic cycles. It is noteworthy that the classical approach was criticized for too much emphasis laid on social factors and not taking into consideration the strategy of companies which have to grapple with internal and external factors (Mahon, Waddock, 1992, pp. 19–32).

A large number of variables and differences between mechanisms blocking the operation of companies are sufficient for a critical approach to the classical cycle of development of a green industrial policy. Also, the fact that companies alone will adopt strategies based on blocking the implementation of various green innovations and development of green technological trajectories should be taken into account. Aside from external pressures, pressures coming the sector itself – e.g. quick shifts in the sector – constitute an important mechanism. Adaptation of new technologies enhances institutional pressures (Penna, Geels, 2012, p. 1002).

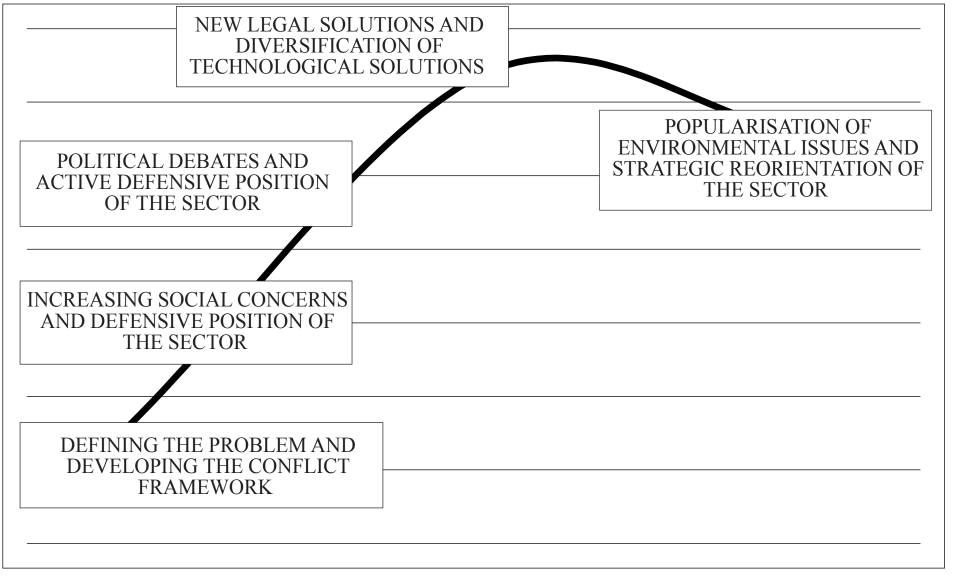
Figure 2. A classical cycle of green policy formulation



Source: Own study.

Given the criticism of the classical cycle, C.C.R. Penn and F.W. Geels went on to put forward a five-stage cycle (See Figure 3). The first stage is concerned with defining the problem and developing the conflict framework. At this stage the most active interest groups begin to voice their concerns about environmental threats. A lack of sufficient identification of factors determining environmental problems and the scope of the negative effects of these threats furnishes conditions for first social conflicts. The standard answer from the industrial sector is defense of their own position and adoption of a strategy based on ignoring or playing down the problem.

Figure 3. Cycle of green policy formulation based on social pressure and industry reaction



Source: Own study.

Of particular note is also the special innovation mechanism terminology which features in analyses concerned with spatial-economic, socio-economic, techno-economic, socio-technical, sectoral, environmental and innovative systems. This terminology will also appear in analyses of technological transitions, including energy transitions. On account of the above-addressed issue of paradigm dominance, which takes place through enforcement of a style and blocking other solutions, such terms as "path dependence" and "lock-in" should be mentioned.

1.5. "*Path dependence*" and "*lock-in*"

In the case of "path dependence" it was presumed that the decision-making processes feature deep and structured historical relations.[3] The decisions made

[3] The publications crucial for the beginnings of the discussion of "path dependence," and which have been used by other researchers to consolidate the issue, include: *Imperial Germany and the Industrial Revolution*" by T. Veblen, *Obsolescence and Technological Change in a Maturing Economy* by M. Frankel, *Economic Growth in France and Britain, 1851–1950* by Ch.P. Kindleberger (Veblen, 1915; Frankel, 1955, pp. 296–319; Kindleberger, 1964). These

and solutions adopted in earlier periods may substantially determine current and future decision-making processes. The dependence may be of a different character, e.g. an institutional, organizational and technological one. It appears that the idea of "path dependence" is close to that which can be observed in the assumptions underlying the *longue durée* historical research, as well as the socio-economic studies of dependism and representatives of the world-systems theory (Cf. Chase-Dunn, 1975, pp. 720–738; Prebisch, 1976, pp. 7–73; Stumpp, Marsh, Lake, 1978, pp. 600–604; Parra-Peña, 1979, pp. 1233–1242; Hopenhayn, 1982, pp. 287–294; Wallerstein, 1974; Wallerstein, 1980; Wallerstein,1989; Czaputowicz, 2007, pp. 150–170). However, in this case the issues of dependence have been reduced to decision-making processes concerned with organizational and technological solutions in individual sectors. The MLP studies, in which "path dependence" as part of the socio-technological regime is one of the main issues, seem to be some kind of a combination of TA studies and a broader spatial and temporal perspective.

The issues of path dependence were spotlighted by, inter alia, W.B. Arthur, who in the text entitled *Competing Technologies, Increasing Returns, and Lock-In by Historical Events* presented competitive mechanisms concerned with adoption of new technologies. In the competition process some organizational and technological solutions may in the first stage gain an adaptive advantage as part of random historical events; in the next stage they gain a consumer acceptance advantage, and then this kind of innovations may limit consumers' possibilities of choice and block other scenarios of development. The consequence of remaining on the dependence path is a "lock-in." Instrumental action with regard to blocking other paths is greatly affected by the profits generated by specific solutions or organizational-technological systems. This kind of monopoly may constitute an obstacle to adopting "better" organizational and technological solutions. In his text W.B. Arthur presents an example of model competition between nuclear technology and solar power technology with regard to the choice of and involvement in it by consumers, while considering the return on outlay costs. A choice of technology in the context of its evaluation with regard to the future is fraught with errors resulting from *ex ante* assumptions; these errors will result

publications provided inspiration for P.A. David, who wrote, inter alia, *Transport Innovation and Economic Growth: Professor Fogel On and Off the Rails* (1969), *Technical Choice, Innovation and Economic Growth: Essays on American and British Experience in the Nineteenth Century* (1975), *Clio and the Economics of QWERTY* (1985), *The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History* (1988), *Path Dependence and the Quest for Historical Economics: One More Chorus of the Ballad of QWERTY* (1997) (David, 1969, pp. 506–525; David, 1975; David, 1985, pp. 332–337; David, Bunn, 1988, pp. 165–202; David, 1997, pp. 3–44; David, 2005, pp. 149–194). P.A. David himself also points to inspirations concerned with the concept of the so-called "Markov chains," A.A. Markov's concept regarding the calculus of probability. The group of authors worth recognition on account of the issues concerned with "path dependence" also includes: W.B. Arthur, R. Cowan, P. Krugman, S.J. Liebowitz, S.E. Margolis, D.C. North, D. Puffert and G.C. Unruh.

from historical events that at a given historical moment cannot be presupposed or predicted. In the case of two energy technologies, whenever they are in competition and assuming that there is at least one historical event, the process of adoption of a technology will depend on the path, if the consequence of a given historical event is exceeding a certain share of a technology so that the share will become a self-propelling mechanism of a technological advantage. An increase in a specific technology share results in a considerable increase in profits; similar profits can be generated with competitive energy technologies being simultaneously adopted. This results from the fact that some of the entities operating on the market may offer and introduce two or more kinds of technology at the same time. In specific situations the market may become divided among various kinds of energy technologies, so that none of them will have a dominant position. In the case of other change sequences, if the market is quickly captured, the development of other energy technologies will get hindered. It must also be assumed that the factor concerned with the quick pace of return on technology development and maintenance outlays will not be sufficient to secure a dominant market position of one technology, although it may enable this (Arthur, 1989, pp. 116–131). However, it is probable that the technology that is the first one to have made considerable progress on the so-called learning curve will gain.

It is also noteworthy that blocking the adoption of a certain technology does not need to concern only various energy carriers, e.g. nuclear and solar energy. W.B. Arthur provides an example of the US nuclear energy sector being dominated by LWR (light-water reactor) technology. This issue was also examined in more depth by R. Cowan in his later text entitled *Nuclear Power Reactors: A Study in Technological Lock-in*. The dominance of LWR technology in the US civilian energy industry resulted from an accumulation of various and vital events and circumstances. The first one of them was the development of that energy technology as part of the nuclear propulsion program for the US Navy ships, the example being *USS Nautilus* (1954), the first nuclear submarine fitted with a PWR (pressurized water reactor). The second one was the position of the participants in the nuclear propulsion program in the American administration. The third one was the involvement of many political entities and the financial support provided for the nuclear propulsion program by the United States Congress (Arthur, 1989, pp. 116–131; Cowan, 1990, pp. 541–567; see also in: Polmar, 1981; Polmar, Moore, 2005).[4] All

[4] R. Cowan writes that in the event of rising demand for energy, the nuclear sector proved to be the answer to the threat to energy security. In those days the LWR was a well-elaborated and ready-to-implement technology owing to the fact that the military sector had earlier expended a large amount of money and work on it. On account of safety, the US government administration supported the LWR technology in Europe as well. The 1950s and 60s witnessed the emergence of three factors enabling diffusion of this kind of technology: (1) discussion of the cost-effectiveness of GCRs (gas-cooled reactors) belonging to Generation I reactors, (2) financial support from the US administration for the construction of reactors in Europe, (3) reactor manufacturers' remarks and action with regard to the reduction of the costs of reactor construction. The 1970s saw a debate on the cost-effectiveness of Generation II reactors; attention was also focused on

this resulted in shutting off other paths of development and in dominance of one of the nuclear technologies. In conclusion one might state that historical events may considerably affect decision making in the future. This in turn means that predictions about the development of energy technologies and future market shares have their theoretical and practical limitations.

The issues concerned with path dependence and lock-in with regard to coal technologies were presented in writings by G.C. Unruh. In the text entitled *Understanding Carbon Lock-In* G.C. Unruh analyzes basic mechanisms for consolidating coal technologies despite rational economic and environmental reasons for choosing different development trajectories. In another text, *Escaping Carbon Lock-in* G.C. Unruh presents mechanisms for overcoming dependence on the coal technology path. In a text co-authored with J. Carrillo-Hermosilla, and entitled *Globalizing Carbon Lock-in*, G.C. Unruh presents an extension of the previous presuppositions, pointing out that countries undergoing industrialization follow the same path of coal technology dependence as industrialized ones (Unruh, 2000, pp. 817–830; Unruh, 2002, pp. 317–325; Unruh, Carrillo-Hermosilla, 2006, pp. 1185–1197). Another text co-authored by G.C. Unruh and entitled *Carbon Lock-In: Types, Causes, and Policy Implications* is an overview of the research into the issues concerned with the lock-in on the path of low-emission technologies, while considering and extending the analysis of the already known blockades that enable the operation of coal regimes. G.C. Unruh and colleagues present conditions, possibilities and strategies supportive of transitions between coal dependence paths and low-emission ones (Seto, et al., 2016, pp. 425–452).

In the case of dependence on the coal technology path, he points out mutual interaction between the related technological, institutional and social forces. Available rational solutions that might be employed by political entities would consist in environment-friendly action and gradual elimination of financial support for coal technology and the fossil fuel mining sector. According to G.C. Unruh, despite the evident benefits of the pursuit of the low-emission path, political entities do not adjust political and economic goals. On the contrary, they often increase the financial and institutional support for the coal technology regime (G.C. Unruh uses the concept of Techno-Economic Complex – TIC). TIC is not merely a simple set of individual technological systems, such as electricity production, distribution and end use. A complex like this should be examined within the context of interaction between public and private institutions. It develops thanks to the established dependence on the energy technology path, also thanks to the processes of mutual adjustment between energy technology infrastructure and all manners of institutions by way of feedback (Unruh, 2000, pp. 817–818).

GCR reactors and heavy-water reactors. Both types of technology presented different problems, which was related to considerable R&D outlay. The newly-developed technologies had to face the already existent and operational LWR technology employed in the civil energy sector (as cited in: Cowan, 1990, pp. 541–567).

Strong dependence of various state spheres on energy constitutes the main problem with regard to making changes to the trajectory of technological development. Direct impact of individual energy systems on people's everyday life results in all political action and decisions becoming costly for political entities. That which seems economically and environmentally rational in the long term is by political entities found to be hardly rational in politics, which is governed by political rationality based on electoral cycles. Making too radical decisions which directly affect voters' lives, and whose consequences on account of political costs are unpredictable is found by political entities to be one of the factors consolidating dependence on a specific technological path.

Apart from political entities that make political decisions, there are also economic entities and social actors (e.g. state-owned and private companies, trade associations, trade unions, scientific institutions, mass media) who likewise have considerable influence on the development of a specific trajectory of energy technology. This can be illustrated with competition for the adoption of the technology of direct and alternating current that took place at the turn of the 19th and 20th centuries. On a metaphorical level, this technological duel was represented by T.A. Edison and N. Tesla, the latter of whom was an entrepreneur as well as an idealist inventor. The scientific dispute also took the form of the "war of the currents" between two companies, the one represented by T.A. Edison (Edison Electric Light Company) and the other represented by G. Westinghouse (Westinghouse Electric Company) (Cf. Hughes, 1983; Jonnes, 2004). A similar situation is to be witnessed in Poland, where the development of coal energy technologies, with regard to the path lock-in, is affected by political entities, economic operators (state-owned companies) and social actors (Cf. Sutowski, 2015, pp. 173–227).

However, it is noteworthy that just like the institutional factor can affect the path lock-in, consolidating the position of coal technologies, it can also cause a new trajectory of the development of energy technology to be opened, for instance by interfering in a particular way in the market operation (Unruh, 2000, pp. 824–825). An institutional kind of impact can be observed at both the international and internal, state level. This kind of institutional impact at the regional level can be illustrated with the energy policy of the European Union with regard to the form of the gas and electricity markets, but also with regard to the requirements concerned with emissions and efficiency of individual sectors of economy. As for the examples of the state's impact on the directions of development of specific energy technologies going beyond coal technologies, these would include Denmark and Germany. From the economic perspective, political entities interfering in the energy market can ensure that the investment risk is reduced to the minimum, to say nothing of the financial support, which on the one hand can enable one technology to be locked-in on the path, but on the other hand – given a change in the direction of support – make it easier for another technology to enter the market. Still, co-evolution of technological and institutional systems posited by G.C. Unruh often results in the institutional system itself being locked-in on the path. An important characteristic of institutional systems is that they are only subject to gradual change over long periods of time (Cf. Williamson, 1998, pp. 23–58).

G.C. Unruh also put forward potential strategies capable of minimizing the blocking tendency of the TIC. In the first place, however, at least some of the limitations that prevent implementation of projects concerned with non-coal or alternative coal technologies should be overcome. This might seem quite difficult, because G.C. Unruh himself refers to coal institutional complexes as the most influential and long-lived ones, which is due to the special links with state-owned institutions (Unruh, 2000, pp. 817–830; Unruh, 2002, pp. 317–318).

In industrialized countries a special kind of support for systems based on fossil fuels is justified with such categories as security, energy supply security and market rationing. G.C. Unruh reckons among the main reasons for path lock-in the following factors: (1) technological ones (dominant installations, projects and patterns, standard systems, structures and components; functionality and cohesion of systems and infrastructure), (2) organizational ones (procedures, trainings, separation of duties, client-supplier relations), (3) industrial ones (sectoral norms, sectoral and technological links, interrelations between innovations and complementary assets in industry), (4) social ones (socialization systems, adaptation of preferences and expectations), (5) institutional ones (the scope of state intervention, legal framework, government administration set-up) (Unruh, 2002, pp. 317–318).

Later on, the division of factors affecting a path lock-in was revised and supplemented. To a greater degree account was taken of the issues concerned with technological transitions, which earlier on in texts by G.C. Unruh – as a category – did not get much coverage. Although invoking the transition was in essence limited to the framework of the transformative theory of institutional change. The text features names of some representatives of studies of processes and changes in the energy industry, e.g. F.W. Geels, S. Jacobsson, J. Schot and V. Smil. Besides, in the new analysis, G.C. Unruh and the co-authors in a special way singled out individual and social behavior patterns and practices which can also be subject to a peculiar lock-in (Seto, et al., 2016, pp. 425–452). With regard to the factor of behavior patterns and practices, account was taken of decision-making processes in relation to individuals' psychological processes, as well as conscious choices which in time become unconscious choices and habits – hardly subject to change, but still possible. Even though studies of practices, behavior patterns and energy awareness draw on methods and findings of psychology, as well as sociology, including even post-structuralist approaches, a more integrated approach is called for. Studies of the issues concerned with the lock-in of practices and behavior patterns proceed in two directions, which may result from personal inclinations of individual researchers or research groups. The first direction focuses on the individual as a subject of influence, while the second direction focuses on practices themselves, which become an object of choice for individuals (Cf. Suchman, Blomberg, Orr, Trigg, 1999, pp. 392–408; Barnes, Gartland, Stack, 2004, pp. 371–377; Shove, Pantzar, 2005, pp. 43–64; Warde, 2005, pp. 131–153; Shove, 2010, pp. 1273–1285; Geels, McMeekin, Mylan, Southerton, 2015, pp. 1–12). Also, research is conducted with regard to behavior patterns in the field of energy industry; the research refers to both psychological and sociological approaches, combining the findings of both the disciplines. Such an approach can be illustrated with the work by a research team at the University of Ontago in New Zealand (Cf. Stephenson, et al., 2010; Lawson, Williams, 2012).

It should be noted that the capacity to overcome the lock-in on the coal technology path will be conditional upon the projected economic and technological profitability as well as upon the period of operation of the technological system, costs of abandonment of individual systems or costs of the choice of alternative solutions. Overcoming the institutional lock-in will depend on the flexibility of institutions, readiness to embrace institutional change, support provided for institutions themselves with regard to alternative trajectories of decarbonization. In the event of overcoming the behavior lock-in, they will depend on the level of motivation or stimulation of motivation. It seems that overcoming habits, preferences and practices necessitates awareness build-up as to alternative behavior patterns (Seto, et al., 2016, pp. 425–452).

Chapter 2

Theoretical aspects of energy transitions and transformations

2.1. The concept of social processes and changes

Energy culture can also be viewed as a process and change concerned with conversion of material and immaterial resources, the result being suitably defined material or immaterial products. The source literature points out differences that appear in the understanding of the concepts of *process* and *change*. The former is about a sequence of events progressing towards transformations, in the case of society – transformations of the social system or its part, however, the process of transformation does not need to be characterized by a long-lasting effect. The latter, that is the concept of change, spotlights qualitative, long-lasting and irreversible transformations of social systems or their parts (Antoszewski, 1999, pp. 193–196; Sztompka, 1999, pp. 39–54). A. Giddens writes that in order to clarify "whether there has been significant change, one needs to demonstrate transformations of the *essential structure* of the object or situation over time. In the case of human society, stating the extent and aspects in which the system is subject to change consists in demonstrating the degree of modifications taking place at a given period within its *basic institutions*. Finding that there has been change is always connected with pointing to permanent elements against which a degree of modification can be measured" (Giddens, 2012, p. 65). There is no doubt that researchers find the empirical distinction and demarcation of changes, as well as pointing to the criteria for their degree to be quite a difficult social change to trace.

It is noteworthy that the source literature presents various typologies of paradigms, theories and models of social change. Still, the majority of these employs similar linguistic and categorial nomenclature used by P. Sztompka. For instance, N. Goodman enumerates such theories as: (1) evolutionary theories, (2) cyclical theories, (3) functionalist theories, (4) conflict theories. At the same time the author differentiates the above-listed theories from theories of modernization and development. J.H. Turner distinguishes models of social change which include: (1) cyclical models, (2) dialectical-conflict models, (3) conflict-evolutionary models, (4) functional-evolutionary models, and (5) post-industrial and postmodernist models. The latter one of the above-mentioned typologies may serve as a summary of various trends the characteristics of which have been synthetically presented above. In the case of the first model the characteristic feature is a repeated nature of events, most frequently with fixed dynamics featuring in periodically recurring events and social phenomena. The characteristic thing about the second model is that it demonstrates social inequalities as the dynamics of change. The third model presents a mechanism of progress from less complex social forms to more elaborate ones, which is an effect of the necessity to fulfil the needs and demands in a given social system. In the fourth model, special emphasis is laid on changes that destabilize or maintain the *equilibrium* of the social system. Social behavior patterns which are reaction to individual kinds of change are taken into consideration. In the latter one of the cases in which included are various models of post-industrial societies, attention is drawn to techno-economic determinants which affect new social configurations. The literature emphasizes lesser methodological sophistication of these concepts, which may result from the fact of the great dynamics of technological changes and their effect on social relations and culture (Turner, 2004, pp. 216–229; Goodman, 2009, pp. 341–344; Geisler, 2009, pp. 381–383). However, the individual model approaches cannot exhaustively elucidate social processes, and so emphasis should be placed on the significance of synthetic approaches which take into account many factors and directions of transformation with regard to both genetic and progressive analyses.

There is no doubt that in the scheme of political and economic sciences, the categories of political or economic *transition* and *transformation* have achieved quite an important position. Some point out that the concepts were introduced in order to get rid of the baggage concerned with the findings of individual scientific schools focusing their research on social change. Another thing that is emphasized here is that the reception of these concepts may be caused by a certain kind of scientific nonchalance resulting from the willingness to follow new terminology, with no prior exploration and thorough exploitation of the findings made in the scope of previous studies of the processes of social change. If we analyze the achievements of the anthropological and sociological studies, it is hard not to agree, at least to some point, with such positions. In corroboration of the instrumental use of the concepts of *transition* and *transformation* one might point to publications that treat them as elements of the title issue, but without any special reflection. Within the trend of rational justification of concepts, it is pointed out – at least on the grounds of political and economic sciences – that the concepts of *transition* and *transformation* are justified with regard to a special kind of social, political and economic transformations in the 1990s. However, one should bear in mind that this kind of change was to be witnessed in, inter alia, post-colonial and Latin American countries earlier (Cf. Blok, 2006, pp. 119–136).

If we accept the distinction between a change and a process, which was mentioned before, then it is noteworthy that by the same token a distinction may be made between other concepts, e.g. the said concepts of *transition* and *transforma-*

tion. A dictionary entry states that a *transition* is a change or transformation of one form or state into another, while a *transformation* is understood as a complete change in form and nature of a specific being (*Transform*, 1993, p. 2427; *Transformation*, 1993, p. 2427; *Transition*, 1993, p. 2428). However, it should be noted that both these concepts have in a peculiar manner been exploited by political sciences, where they were strongly tied to the changes and processes in the socio-political systems (Cf. Blok, 2006, pp. 108–271; Antoszewski, 2011, pp. 1–12; Winiecki, 2012, pp. 85–254). Another group exploiting the categories of *transition* and *transformation* is the one of economists, who link transformations of political systems with transformations of economic systems (Cf. Bałtowski, Miszewski, 2006; Blok, 2006; Gomułka, 2016). A debatable thing here is, however, that both the terms are often used interchangeably, without regard for the above-delineated distinction. Frequently, these two terms are exploited instrumentally, only with a view to emphasizing the considerable dynamics of cultural, social, political, economic, technological and other processes.

2.2. The concept of energy transition and transformation

As we hear about social processes and change, we usually assume that they are about long-term and in-depth transformations, which can be illustrated with agricultural or industrial revolutions. Also, processes of social change are often presented from the aspect of technological innovations, which are in turn explained in systemic, structural, evolutionary, cyclical and other approaches.

Undoubtedly, studies of the processes and changes in the energy industry reflect the same theoretical and methodological problems as the ones that are the object of scientific debate in the research into the social, political and economic processes and changes. The cause of this state of affairs can be traced back to the manner in which elucidations and interpretations are constructed. In individual fields and disciplines it is only natural that processes and changes themselves in the political, social and economic sphere also constitute significant determinants in the processes and changes in the energy industry. Apart from treating individual spheres as fundamental determinants, the individual spheres may also be treated as separate trajectories of development. As part of the manner of constructing studies of processes and changes, attention should be drawn to the fact that similarities in analyses may follow from purely instrumental measures. The above-mentioned instrumentalism may take the form of a simple analogy that obviates the need to create new categories, typologies and classifications, or may constitute natural continuation in the process of looking for genetic continuity in the studies of processes and changes.

Making use of the earlier and established reflection in the studies of social, political and economic processes and changes involves pointing to the same problems in the analysis of energy transformations, which include, inter alia: (1) permanence and impermanence of transformations, (2) cumulativeness and accumulativeness of transformations, (3) unilinearity, multilinearity and cyclicity of transformations, (4) dynamics of transformations, (5) determinants of transformations. Furthermore, the studies of energy trends appear to be trying to overcome two extreme positions that were present in the research into the dynamics of political change as a special kind of social change. Hence, on the one hand there is the willingness to avoid a linear vision of irreversible and objective progress. On the other hand, there's the willingness to avoid functional and systemic visions of change that would come down to increasing the significance of some functions of the system, e.g. exploiting natural, technological and cultural resources, while decreasing the significance of other functions, e.g. functions concerned with stabilization of the system (Cf. Pałecki, 1992, pp. 85–93; Turner, 2004, pp. 216–229; Sztompka, 2005; Geisler, 2009, pp. 381–383; Goodman, 2009, pp. 341–344).

Just like in the case of studies of processes and changes in politics, in the studies of energy trends there was a problem concerned with application of proper terminology that would capture the essence of this kind of trends, which could be illustrated with the co-occurrence of such terms as 'transition' and 'transformation.' Use of these two terms can be interchangeable, but it may also be determined by world-view inclination, or it may be an expression of a certain methodological-theoretical position.

An attempt at pointing to fundamental differences between the terms of *transition* and *transformation*, used in the studies of energy processes and changes, was made by, inter alia, K. Hölscher, J.M. Wittmayer and D. Loorbach in the text entitled *Transition versus transformation: what's the difference?* The authors point out that the term 'transition' is used by energy trend researchers who focus on analyses of sustainable development, while the term 'transformation' is used by researchers who in their analyses point to a special kind of dynamics and intensity of energy trends. Therefore, stressing a special kind of term in the analyses should be connected with specific methodological-theoretical positions. If a determinant concerned with the use of the two terms is the degree of intensity, and the scope of energy processes and changes, then the term 'transition' is concerned with the narrowing position, while the term 'transformation' is concerned with a broader position (Hölscher, 2017; Hölscher, Wittmayer, Loorbach, 2017; Wittmayer, Hölscher, 2017, p. 8 and the following pages). However, it is noteworthy that the terms 'transition' and 'transformation' frequently do not express any research position, as they are only linguistic devices employed to notionally consolidate many terms used to define various energy trends. In addition, using the terms 'transition' and 'transformation' may be associated with the willingness to avoid using other terms which might carry worldview inclinations or methodological-theoretical positions (Cf. Graczyk, 2016; Młynarski, 2017, pp. 75–85). One might also point to an attempt at juxtaposing the two terms with regard to their essence, which can be illustrated with the discussion by U. Brand, F.W. Geels, J. Schot and A. Stirling (Geels, Schot, 2007, pp. 399–417; Brand, 2014, pp. 242–280; Stirling, 2014a, pp. 1–23).

The term 'transition,' as applied in the context of analysis of sustainable development, is used by, inter alia, J. Rotmans, R. Kemp, M. van Asselt. These authors understand a transition as a radical shift from one social regime to another; it may also constitute a process of targeted changes the aim of which is to attain sustainable development (Rotmans, Kemp, van Asselt, 2001, pp. 15–31). The assumption underlying the authors' analyses is that sustainable development alone requires radical changes in the functional respect. But a functional change alone would not be enough, because the situation calls for changes to public policy, as well as to social awareness and social relations (Kemp, Loorbach, Rotmans, 2005; Kemp, Loorbach, Rotmans, 2007, pp. 1–15). According to these authors, individual public policies are highly fragmented, which results in a lack of efficiency at coping with contemporary socio-economic problems, and with strategic and long-term planning. Of great significance is therefore methodical control of shifts, but with a long-term perspective in view. For this to be possible, in the first place, alternative trajectories of social development should be identified, so that "adaptive programs" can be appropriately implemented, for instance with regard to making use of resources, energy and transport.

In A. Stirling's approach a 'transition' is one of the forms of radical social change. It is often an effect of adoption of technological innovations and targeted political action coupled with proper use made of scientific knowledge and knowledge of some other kind. An example of this kind of change can be furnished by the development of nuclear energy, combating climate change, new ways of using resources and sustainable intensification of agricultural production (Nuttall, 2005; Fleming, 2010; Stirling, 2014a, pp. 1–23). A. Stirling finds a 'transformation' to be another form of radical social change. This kind of change is concerned with the co-occurrence of various trajectories of development and social and technological innovations. A transformation may take place when social practices and values get changed, and so changes in awareness, persuasions and culture may affect practices concerned with the use of energy and conservation (Stirling, 2014a, pp. 1–23). While distinguishing between the two terms, emphasis is laid on greater intensity and a broader scope of social and technological innovations (Cf. Seyfang, Haxeltine, 2012, pp. 381–400). A. Stirling also points out a considerable role played by political factors in energy processes and changes. An energy transformation becomes both a cultural and political challenge, as well as an object of competition for various social and political entities. The discursiveness of energy projects makes trajectories of energy processes more superficial and less real; they can thus become a mere façade for imposing other solutions which do not necessarily carry much weight for sustainable development (Stirling, 2014b, pp. 83–95).

Despite the presupposition whereby processes may be non-linear or untargeted, in the majority of analyses, with regard to energy trends, it is posited that transitions and transformations are characterized by their peculiar patterns, regularities and recognizable mechanisms. It is still noteworthy that K. Hölscher, J.M. Wittmayer and D. Loorbach refer to energy transitions as shifts between various states, which can generate change patterns. According to these authors, in the studies of transitions, shifts between individual states are non-linear, which would unavoidably result in the assumption that they are not steady, but are irregular and abrupt. This assumption follows from the fact that in the theory of social change there is a difference between multilinear, non-linear and untargeted processes (Hölscher, Wittmayer, Loorbach, 2017). According to K. Hölscher, J.M. Wittmayer and D. Loorbach, in the energy transition, as part of the analysis of shifts, it would be advisable to point to patterns that facilitate or hamper these shifts. Furthermore, examples of such analyses include multi-level and multi-stage concepts, among which reckoned should be concepts by F.W. Geels, J. Schot as well as J. Rotmans, R. Kemp and M. van Asselt. In the case of the latter three scientists, they represent an attempt at combining a multi-level concept with a cyclical approach to social processes (Rotmans, Kemp, van Asselt, 2001, pp. 15–31).

In the context of the issues concerned with energy, processes and changes are also analyzed from the Marxist and neo-Marxist (as well as their structuralist, post-structuralist and post-modernist variants) perspective, or in the scheme of movements that engage in polemics with them. Depending on the emphasis placed on the factors affecting the trends, at least two positions within the Marxist movements can be distinguished; the first one is a materialist position (which persists in a more or less traditional interpretation of Marxism), while the second one is a non-materialist position (which overcomes the commonly accepted determination in historical materialism, that is the so-called critical approaches). Depending on the approaches, in individual analyses, attention is drawn to, inter alia: (1) conflicts between citizens and the energy industry, (2) a relation between a specific state of productive forces (energy resources, energy technologies) and a specific state of relations of production (a manner of production division in the energy sector, a manner of labor division in the energy sector), (3) ownership relations and privileges in the energy sector (while taking into account differences between individual energy sectors), (4) conflicts as part of the relations of production (conflicts between various kinds of energy sectors), (5) evaluation of individual elements of productive forces (protection of energy and environmental resources), (6) appropriation of the added value as part of the so-called "green economy" and "green energy," (7) externalization of environmental costs at the local, regional and global levels, (8) significance of ideology and awareness in the control over energy processes and changes. These approaches often refer to various kinds of conservation trends (e.g. revolutions, transformations, transitions, changes) and trends that allow for sustainable development. In addition, they present both an optimistic attitude towards processes and changes – e.g. with regard to evaluation of the development of renewable energy sources in post-industrial and developing countries – and a pessimistic attitude – with regard to continued exploitation of energy and environmental resources (Cf. Wallerstein, 2004; Burkett, 2005, pp. 34–62; Wallerstein, 2008;

Burkett, 2009; Burkett, 2016, pp. 73–96; Foster, 2005; Artus, Virard, 2008; Wedel, 2008, pp. 185–193; Borgnäs, et al., 2015; Foster, 2015; Fücks, 2016; Malm, 2016; Leonardi, 2017; Moss, Becker, Gailing, 2016, pp. 43–68; Saito, 2017).

In the case of multi-level and multi-stage concepts, but also in the case of systemic concepts of energy transition and transformation, a frequent reference is made to complex adaptive systems (Hölscher, Wittmayer, Loorbach, 2017). The differences that result from the application of separate terms of 'transition' and 'transformation' to energy processes and changes have relevance for the articulation of the main items in adaptive systems. Discrepancies may result from both research views and the essence of complex adaptive systems. After all, they are like wide-ranging sets including various kinds of causal agents. The essence of social entities as well as of other entities is that it is impossible to accurately predict the effects of their action. Moreover, changes at lower levels or in subsystems may affect overall or global changes, with simultaneous co-occurrence of feedback from the system as a whole. Systems of this kind may therefore feature a phenomenon of determinist chaos, or a lack of any change, or proportional change. The complexity of the systems may lie in the fact that it is difficult to point to their boundaries; they are open, dynamic, and each one of the subsystems may have features of complex systems (Cf. Miller, Page, 2007; Gros, 2008). Invoking features of complex adaptive systems (CAS), as part of multi-level and multi-stage concepts presenting the issues concerned with energy transitions or significance of technological innovations, may result in a lack of real explicatory power of these concepts.

The main processes and changes within complex systems include: (1) emergence, (2) coevolution, (3) self-organization. In the first case – emergence – given self-organization of simple component elements of the system, new action forms, patterns and practices are created at the overall level. Description of individual, smaller elements or subsystems does not make it possible to indicate properties of the system as a whole. Thus, emergence is a process of appearance of new structures, patterns and practices that determine new properties of the system as a whole. The idea behind emergence is therefore a presupposition whereby there can be autonomous properties at the highest level of the system, which cannot be understood by simple reduction to lower levels in the system. In the second case – coevolution – processes encompass the influence of each one of the elements on the other ones in the system, but these relations may be both positive and negative. The last kind of processes is self-organization, which is about spontaneous self-ordering of the system elements. Without external factors, and only through internal expansion of the structures, patterns and practices, the system increases the level of its complexity. J. Rotmans and D. Loorbach write that self-organization constitutes a capacity to create new system structures which are dissipative[5] (Sawyer, 2005; Miller, Page, 2007; Rotmans, Loorbach, 2009, pp. 184–196).

[5] J. Rotmans and D. Loorbach directly refer to the concept of dissipative structures, presented by I. Prigogine. In his view, dissipative structures are the ones in which the energy of ordered

A certain kind of typology of transition trajectories as part of an MLP was presented by F.W. Geels and J. Schot in the text entitled *Typology of Sociotechnical Transition Pathways* (Geels, Schot, 2007, pp. 399–417). This typology along with a differentiation of transitions is based on two dimensions. The first one is time, while the other one is a level of interaction, which is concerned with three main levels distinguished within an MLP. The first kind of change is **reproduction**, the second one – **technological substitution**, the third one – **transformation**, the fourth one – **reconfiguration**, while the last kind of change is a **shift and restabilization.**

In the case of reproductive changes, in the absence of pressure from the landscape, the regime remains stable and will regenerate. There may be radical innovations in technological niches, but they are in no position to come to the surface and become part of the energy regime. Of great relevance for the stabilization of this system is the state of the landscape, as well as possibilities of solving individual problems by the regime itself. Nevertheless, energy regimes are characterized by certain dynamics related to the operation of energy sectors, energy markets and individual energy companies. Hence, there are investment processes, market competition and development of new products, which ultimately in the course of time may give rise to effectiveness in the energy regime (*Ibidem*, p. 406).

The second transition trajectory is technological substitution, which is based on appropriate pressure from the landscape, a "special shock," or a "disruptive change" which results in opening a window of innovation to technologies developed in niches. As a consequence of adequate development of innovations and favorable circumstances, change in the energy regime takes place. This results from the presupposition that energy innovations elaborated in niches often encounter the stable dynamics of energy regimes, which are not that radical changes. Therefore, pressure from the landscape, which arouses tension in the regime, is needed to open windows of innovation. As a result of innovations entering the technologies of the mainstream, stable technologies begin to defend their positions with the aid of their own improvements (Geels, Schot, 2007, pp. 409–411; Sovacool, 2016, p. 205). A phenomenon of this kind was known earlier in the studies of innovation, and was referred to as the "sailing ship effect" or the "red queen effect." As for the term of the "sailing ship effect," it was coined by W.H. Ward in the 1960s, although

processes gets dissipated and converted into energy of unordered processes (a change in the energy of the system). If in the system, in a state far from equilibrium, maintenance of a stable stationary state far from equilibrium may result in a bifurcation of the system. After the system's equilibrium has been lost, a transition into other stationary states may ensue. Such processes allow for maintenance and emergence of organized structures in short periods. For such structures to be maintained, constant exchange of energy with the surroundings is required. The emergence of phenomena bringing states far from equilibrium in fact results in processes of organization – spontaneous self-regulation. This means that in open systems dissipation may contribute to an increase in organization, which results from the fact that given the bifurcation of the system, dissipation gives rise to emergence of momentary structures (See Prigogine, Stengers, 1990; Rotmans, Loorbach, 2009, pp. 184–196).

the phenomenon itself had been observed decades earlier by S.C. Gilfillan in his publication entitled *Inventing the Ship*. The sailing ship effect is concerned with changes in the field of transport and energy technologies which took place in the 19th century. According to W.H. Ward's analyses, over a period of five decades as from the advent of the steamship, the sector of sailing ship construction witnessed more improvements than over the period of the previous three centuries. Currently, this proposition is being questioned on account of more detailed analyses of innovation in the 19th-century transport.[6] Still, the term has come to be bound up with innovation practices consisting in attempts at pre-empting or reducing to the minimum the losses incurred as a result of the introduction of new technologies in the mainstream market. Thus, the old technology undergoes revitalization, which takes place in conditions that might be vividly referred to as the "last gasp" (Gilfillan, 1935; Gilfillan, 1970; Gilfillan, 1971; Parayil, 2002).

A third kind of transition trajectory is a transformation, which is based on stimulation of the active entities in the technological regime by the landscape. The aim of this influence is to cause the entities to correct the structure of the technological regimes in a situation where niche innovations have not reached a satisfactory level yet (Sovacool, 2016, p. 205). The landscape influence often runs up against defiance, and so it is bound up with all manner of conflicts and opposition strategies.[7] In the event of moderate landscape pressure and when the

[6] Some research points out that the "sailing ship effect" may have resulted from other factors. For instance, J. Howells claims that the period in question witnessed quick divisions of the transport market, and so sailing ships and steamships may not have been engaged in the competition the way W.H. Ward saw it. Besides, the improvements pointed to by W.H. Ward may have resulted from the competition itself within the sailing ship transport sector only. Also, attention is drawn to the research proving that improvement in the sailing ship transport happened prior to the period stressed by W.H. Ward. According to J. Howells it is only in in-depth research that one can see that innovation concerned with the old technology does not require emergence of threat from new technologies. Hence, J. Howells points out that there are two key interpretative problems that mislead various authors into believing that the "sailing ship effect" has taken place. Firstly, in long time-frames it is possible to overlook the fact that none of the co-existent technologies – whether old or new ones – is of a static character. Secondly, there may be a problem of differentiation of what constitutes a spontaneous improvement within an old technology, and what results from a new technology. There is then the problem of factors concerned with the natural process of innovation, intra- and inter-sector competitiveness. That is why in the research into innovation, a motivation for the innovation of the old technology needs to be specified so as to demonstrate the "sailing ship effect." It is also noteworthy that presented are mathematical models of the effect, which provide arguments for its occurrence in the sphere of technological innovation, which can be exemplified with the works by N. De Liso and G. Filatrella (Howells, 2002, pp. 887–906; Howells, 2005; De Liso, Filatrella, 2008, pp. 593–610; De Liso, Filatrella, 2011, pp. 563–580; Mendonça, 2013, pp. 1724–1728).

[7] For instance, in his text entitled *The hygienic transition from cesspools to sewer systems (1840–1930): the dynamics of regime transformation* F.W. Geels presents a conflict between various entities, that is social entities and entities concerned with public authority. F.W. Geels' text is a case study of a technological transition that encompassed a shift from a system of cesspools to a sewer system in urban developments in the Netherlands between the mid-19th century and the mid-20th century. External criticisms coming from outside the regime were related to negatives assessments

niche innovations have not yet attained a sufficient level, entities in the technological regime begin to modify development paths with regard to innovation. Moderate changes in the landscape exert an influence on the entities operating in the regimes so that they modify their own practices. Changes in the landscape are significant only insofar as they have been identified and adopted by individual entities in the technological regime. Of great importance are also entities outside the regime, because they explain changes and threats that can be properly identified within the regime. A significant role is therefore played by various pressure groups and their skills at encouraging the public opinion. Public discussion of alternatives and presentation of views may affect perception of the technological regime, and ultimately lead to changes to development paths (Geels, Schot, 2007, pp. 406–408). An example of this kind of activity may be the influence exerted by ecomovements, health food movements or movements advocating healthy life-style in general. The axiology of this kind of grassroots movements and their environment-oriented activity was quickly taken over by the mainstream of the technological regimes, which can be illustrated with the segmentation of the food market, allowing for the so-called health food, as well as the expansion of innovativeness in the field of technologies supporting a healthy life-style, e.g. fitness trackers (Cf. *The Future of Eco-innovation*..., 2012, pp. 2–20; *Health wearables*, 2014, pp. 1–9; Anzaldo, 2015, pp. 1–5; Hui-Wen Chuah, Rauschnabel, Krey, et al., 2016, pp. 276–284; Kumar, 2017, pp. 5–82).

A fourth kind of transition trajectory is reconfiguration, based on symbiotic niche innovations which have been adapted in the technological regime and lead to further structural corrections as a result of the landscape pressure (Geels, Schot, 2007, pp. 411–413; Sovacool, 2016, p. 205). Symbiotic innovations pass on to technological regimes, e.g. energy-related ones, because they are useful in solving local problems. Their usefulness is the effect of their straightforward adoption as an additional innovation or a replaceable technology. Frequently, no substantial financial outlay is involved, but these innovations increase effectiveness and solve some of the problems in the regime. If the changes do not considerably affect the energy regime, preserving its structure, then a transformation is the case. However, changes may be of a more extensive character and lead to further adjustments. This is facilitated by the activity of the regime entities, which carry out tests with regard to the possibilities for combining old and new technologies. Such tests engaged in by entities enable further technological changes, as well as shifts in awareness and practices embraced by technology users. In turn, the processes tap into the potential concerned with new applications of niche innovations. Hence, over time

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of living conditions made by doctors, as well as to demands made with regard to changing the status quo, while the opposing stance was presented by municipal authorities, town councils and departments of public works. Doctors associated unhygienic conditions with the incidence of infectious disease in towns, which became a foundation for criticism of public authorities. On the other hand, in the early stage public authorities showed some opposition by downplaying the problem (Geels, 2006, pp. 1069–1082; see also: Mokyr, Stein, 1997, pp. 143–205).

and under the influence of the landscape, changes of individual elements trigger reconfiguration of the whole technological regime. In the case of both transformation and reconfiguration, a new regime arises out of the old one. However, in the case of reconfiguration, significant changes in the structure of the technological regime follow. The changes take place in the dispersed systems within the regime, e.g. in agriculture, transport, metallurgical industry, chemical industry, among which mutual interaction arises. Changes in the individual systems are an effect of the appearance of one ground-breaking technology, and are concerned with the sequences of implementation of many innovative components (Geels, Schot, 2007, pp. 411–413).

The last type of transition trajectory is concerned with a shift and restabilization, in which landscape pressure is of substantial significance. The landscape impact results in destabilization of the technological regime, if the niche innovations are not sufficiently developed. Over a longer period of time, when various niche innovations co-exist, reconstruction of a new regime takes place. One of the niche technologies gains ascendancy, becoming the center for a new technological regime (Sovacool, 2016, p. 205). Abandonment of the leading technology and reorientation in the technological regime towards a new trajectory takes place when problems in the technological regime begin to pile up, which in turn arouses entities' doubts as to the reasonableness of the rules and development directions. At the same time, a lack of proper niche innovations which might be adapted on account of open windows results in the protraction of this state. In this period niche innovations engage in competition for support and acceptance within the regime. Under the considerable influence from the landscape, structural splits within the technological regime take place. As they discern the regime's slight effectiveness in solving the main problems, political entities cease to support it (Geels, Schot, 2007, pp. 408–409). A lack of rules and criteria for the choice of development paths results in inadequate optimization of political decisions. Under such conditions of destabilization, as well as co-evolution or competition between niche innovations, one of them begins to be dominant, and in consequence stabilization and institutionalization of the new technological regime follow. By way of exemplification of the abandonment of technology and reorientation in the technological regime, F.W. Geels invokes a transition trajectory progressing from the horse-drawn vehicle to the automobile in the USA in the period between the mid-19th century and the mid-20th century (Geels, 2005, pp. 445–476; see also: Maxim, 1962; Flink, 1970; Gartman, 1986; Mom, 2013; Mom, 2015).[8]

[8] According to F.W. Geels at some point in their development horse-drawn vehicles in US urban areas encountered some problems, e.g. animal waste, people's increased mobility coupled with a development of towns, increasing costs concerned with the maintenance of horse-drawn tram/horse-drawn railway facilities. Electricity-based niche technologies took advantage of these problems, thanks to which urban transport was able to develop on the basis of electric trams. In the case of all transport, of great significance were niche technologies which harmonized with the development of the new mining industry, which could be exemplified by the development of road transport on the basis of crude oil (Geels, 2005, pp. 445–476).

2.3. Studies on energy transition and transformation

Interest in research into long-term changes in the exploitation of resources and energy technologies goes back as far as the 1960s. One of the most important reasons for studies of this kind was the willingness to present valuable forecasts in respect of both quality and quantity. For this purpose, use was made of economic theories, theories concerned with exact sciences, as well as empirical historical studies. The prime examples of these include theories of technological substitution and economic cycles as well as *longue durée* perspectives (Cf. Schurr, Netscher, 1960; Fisher, Pry, 1971, pp. 75–88; Marchetti, Nakićenović, 1979, pp. 1–69).

Synthetic analyses within the scope of studies of energy transition were presented by, inter alia R.C. Allen, A. Cherp, R. Fouquet, A. Grübler, J. Jewell, P.J.G. Pearson, B.K. Sovacool (Allen, 2012, pp. 17–23; Cherp, et al., 2018, pp. 175–190; Fouquet, Pearson, 2012, pp. 1–7; Grübler, 2012, pp. 8–16; Sovacool, 2016, pp. 202–215). A. Grübler pointed out two directions of research, which are innovative with regard to the development of studies of energy transition. In the first group he included research into global and international changes in the energy structure, while in the second group he included research into changes in national energy structures (Grübler, 2012, pp. 8–16). According to A. Grübler ground-breaking analyses concerned with various levels of energy structures should include a publication by P.C. Putnam entitled *Energy in the Future*, in which the author evaluates the use of traditional carriers as part of the use of primary energy (Putnam, 1953). P.C. Putnam's publication appears to be one of the first ones which in a comprehensive manner and within such a scope characterize a transition from traditional energy carriers to carriers of a new kind. Other significant analyses include publications by J. Darmstadter, P.D. Teitelbaum and J.G. Polach, as well as a short statistical research paper by H.-D. Schilling and R. Hildebrandt (Darmstadter, Teitelbaum, Polach, 1971; Schilling, Hildebrandt, 1977, pp. 8 and the following pages). However, the first comparative research work which presented modelling of transition periods in the energy sector was a publication by C. Marchetti and N. Nakićenović (Marchetti, Nakićenović, 1979, pp. 1–69).

The proposition following from the work by C. Marchetti and N. Nakićenović is that the energy industry features "time constants of change" which take the form of fluctuations appearing within 5–10 decades. While analyzing the processes of carrier substitution in energy structures, at least several tendencies should be considered: (1) permanence of trends of energy substitution and energy technology, (2) differences in tipping points of energy substitution and energy technology, (3) existence of time constants for processes of energy substitution and energy technology, (4) existence of limitations in the forecast about energy substitution and energy technology for new sources and technologies, e.g. nuclear energy (*Ibidem*, pp. 1–69).

First and foremost, attention should be drawn to the fact that a new carrier as part of the primary energy structure – like in the case of new technology – has a chance to come into use thanks to support of the capital that comes from various sectors of the economy. Investments in projected profits which may come from an increased level of energy efficiency often quickly penetrate the market. Subsequently, the rate of investment slows down, and then again speeds up. In this period a new energy sector is being formed; it needs to consolidate its market position by itself. According to C. Marchetti and N. Nakićenović, the tipping point in this period is a 2–3% market share. If the diffusion of a carrier or technology does not reach this level, then in the future its progress will have to be established on the basis of variables and indexes of a different kind. Apparently, in a situation like this, a time constant could be a useful index, as it would be characteristic of other energy substitutions and energy technologies of the same kind. In the presented analyses, differences in the periods which have relevance for the emergence of tipping points for substitution may also be visible. For instance, the tipping point in the case of gas may be a 10% market share. Differences in the course of diffusion of energy carriers and energy technologies should therefore become the focus of in-depth studies, so that their specificity can be indicated. One of the premises that could be brought up as a determinant of this state is limitation of the gas transmission and distribution infrastructure, and by extension the capacity to use gas in a variety of areas. According to the research by C. Marchetti and N. Nakićenović it is possible to point out the time constant, that is a period of progress from 1% to 50% of the market share, which is supposed to be around 100 years. However, account should be taken of the differences that can appear in analyses of individual countries, which can be exemplified with the substitution processes in Germany (*Ibidem*, pp. 1–69).

Studies of substitution factors may be difficult due to inter-permeation of many trajectories of energy substitutions and energy technologies. For instance, crude oil achieved a substantial market share when coal still had a considerable growth potential; interestingly, the situation was similar in the case of coal when it was replacing wood. It is noteworthy that justification of this kind of change with the aid of political factors may be insufficient, and it may likewise not be sufficient when attempts are made to justify the changes with the aid of price factors. The research conducted by C. Marchetti and N. Nakićenović makes it possible to point to the following conclusions which do not fit in with similar, previous analyses, and by extension significant contribution to the studies of the processes of energy substitution and energy technologies: (1) a relatively quick phase-out of coal as part of the primary energy structure, (2) great significance of gas in the period of the next 50 years, (3) less significance of such sources as geothermal and solar energy, which results from a long period of adaptation in the system (*Ibidem*, pp. 1–69). A. Grübler and N. Nakićenović decided to examine one of the mentioned propositions about the significance of gas more thoroughly, using the example of the USA, in the shared text entitled *The Dynamic Evolution* *of Methane Technologies*. In it, the authors point out that the processes which make it possible to overcome the difficulty in developing gas technologies as independent and not derivative of oil technologies are possible and should be based on the specialization of the gas and oil sectors. The presented forecasts show that gas may become a basic carrier in the next decades. What is more, some analyses point out that gas technologies are still on the rise. However, in the case of a presentation of a new model of energy substitution and energy technologies, including gas-related ones, A. Grübler and N. Nakićenović estimate that "time constants" are to be around 70 years for all the energy carriers. Market saturation time intervals between coal, oil and gas technologies are about 50 years (Grübler, Nakićenović, 1988, pp. 13–41).

A. Grübler also reckons the research work by A. Kander, P. Malanima and P. Warde entitled *Power to the People: Energy in Europe over the Last Five Centuries* among ground-breaking global and international analyses. The publication presents transformations in energy structures of Europe and individual European countries in the era of pre-industrial economy and the first industrial revolution, as well as during the second and third industrial revolutions (Kander, Malanima, Warde, 2014). Also, P. Malanima presented a comparative analysis of changes in the energy system in Europe and other areas from the historical perspective, that is in the pre-industrial period and during the first industrial revolution, in the text entitled *Energy crisis and growth 1650–1850: the European deviation in a comparative perspective* (Malanima, 2006, pp. 101–121). Irrespective of the division introduced by A. Grübler, emphasis might also be laid on the great significance of the studies done by international organizations and other institutions which conduct their research into energy policy, energy security, energy efficiency and overall changes in the energy industry. Hence, it is worth mentioning such institutions as BP, EIA, IEA, IAEA, OECD, the UN and the EU.

The second research group isolated by A. Grübler is made up of research into national energy structures. According to this author, in the case of the USA, the first innovative works are concerned with research done by S.H. Schurr and B.C. Netscher – at this point it is worth mentioning their publication entitled *Energy in the American Economy, 1850–1975. An Economic Study of its History and Prospects* (Schurr, Netscher, 1960).[9] The assessment of this publication is likely to bring a positive result, both in the prognostic aspect and on account of

[9] It is noteworthy that S.H. Schurr is also an author of the work entitled *Energy in America's Future: The Choices Before Us,* which was published almost two decades later than the work entitled *Energy in the American Economy, 1850–1975. An Economic Study of its History and Prospects*. This publication contains a comprehensive discussion of the US energy structure from the perspective of the following issues: (1) energy consumption, (2) an overview of historical trends in the energy sector, (3) energy flow in the economy, (4) influence of energy on the development of the economy, (5) significance of energy efficiency, (6) forecasts of energy use, (7) significance of energy carriers and their future (Schurr, Darmstadter, Perry, Ramsay, Russell, 1979).

the fact that it provides valuable quantitative data on the US energy industry. The research was drawn on by, inter alia, J. Fisher in his publication entitled *Energy Crises in Perspective* (Fisher, 1974), but also more contemporary researchers and analysts such as R. Cherif, F. Hasanov and A. Pande. In a text entitled *Riding the Energy Transition: Oil Beyond 2040* the latter ones of the mentioned researchers attempt a qualitative and quantitative analysis of the transition in the US transport sector. The changes were seen as a shift, in transport, from an oil-based energy technology to a technology directly based on electricity. The effect of this kind of energy technology substitution in transport would be a shorter life cycle of oil as a fuel. At the same time, it can be assumed that this can result in prices falling down to the level of prices of coal (Cherif, Hasanov, Pande, 2017, pp. 2–31).

Among the contemporary synthetic analyses of energy transitions in the USA reckoned should also be a text by P.A. O'Connor and C.J. Cleveland. The authors present a US energy transition in the period of 1780–2010 through the prism of consumption of traditional energy and energy conveyed by carriers of a new type. P.A. O'Connor and C.J. Cleveland also considered the issues of the energy intensity of the US economy, which changes over time; however, the years 1880–1920, as the authors conclude, witnessed stagnation in the trend of energy intensity changes. The stagnation resulted from, inter alia, an ineffective use of steam energy, but the innovative processes within the energy service technology changed the state of affairs (O'Connor, Cleveland, 2014, pp. 7955–7993). C.J. Cleveland also co-authored, along with other researchers, a text entitled *Energy and the U.S. Economy: A Biophysical Perspective*, which presents a synthetic analysis of the relation between a national consumption of energy and the US economy. The analysis adopts a hundred-year research perspective, that is from the end of the 19th century till the 1980s, taking into consideration cross-sectional data from more than 80 economic sectors in the years 1963, 1967 and 1972. The authors observed that the increase in energy efficiency was linked with the economy's capacity to use higher quality fuels and electricity. Another factor affecting the energy efficiency was relative changes in the use of fuels in individual economic sectors. And hence it can be concluded that the return on investment in energy became the main driving force behind the US economy. However, the USA witnessed a drop in the rate of return on money invested in the main fuels in the economy, which is attested by the data presented by the authors.[10] The text by C.J. Cleveland and co-authors presents a few hypotheses relevant for the analysis of the energy transition in the USA: (1) there is

[10] An in-depth analysis of the issues concerned with the Energy Return on Investment (EROI) was presented by Ch.A.S. Hall in the work entitled *Energy Return on Investment A Unifying Principle for Biology, Economics, and Sustainability*. Ch.A.S. Hall's publication presents the issues of EROI in a broader context, that is in the physical context (the laws of thermodynamics), in the biological context (metabolism, evolution) and in the economic context (significance of energy in the pre-industrial and industrial economy). Besides, Ch.A.S. Hall took into consideration the analysis of the methods of determining the EROI, the factors affecting the EROI and the criticism of the studies of the EROI (Hall, 2017).

a strong relationship between energy consumption and production in the economy (there are also disparate hypotheses), (2) labor productivity in the USA in the 20th century was affected by better use of manual labor as well as increased use of fuels in the economy, both in the quantitative and qualitative respect, if only thanks to new technologies, (3) costs of energy production influence the increase in the prices in the economy, which can also be affected by a fiscal policy, (4) costs of energy production rise and will rise despite technological innovations: (a) this may impact the supply of energy-intensive products in the economy, (b) costs may change on account of technological innovations that extend access to energy (Cleveland, Costanza, Hall, Kaufmann, 1982, pp. 890–897).

Of great relevance for the studies of energy transitions is work concerned with changes in energy structures in the pre-industrial era and periods of industrial revolutions in the territory of the United Kingdom. Because of the dominance of the coal paradigm, a bulk of historical research works focused on coal and its connections with other sectors, e.g. with industry (Cf. Nef, 1932; Beaver, 1951, pp. 131–148; Hannah, 1979; Allen, 2009; Allen, 2012, pp. 17–23). The research that overcame the coal perspective by including in the long-term analyses the significance of energy services is to be related to the publications by R. Fouquet and P.J.G. Pearson. A characteristic trait of their works is a perspective of long duration which considers changes in the services of end use of lighting, transport and energy supply. The presented characterization of energy structures is coupled with analyses of energy efficiency and costs of energy and energy technologies (Fouquet, Pearson, 2003, pp. 93–110; Fouquet, Pearson, 2006, pp. 139–177; Fouquet, 2008; Fouquet, 2011b, pp. 4–12; Fouquet, 2014, pp. 186–207; Fouquet, 2015, pp. 147–156). Undoubtedly, it is worth mentioning a publication which has already become a classic – a work by W.S. Jevons, which is not at all mentioned by A. Grübler. This publication, authored by an English economist and science propagator, was issued in the mid-1860s, and is of great relevance for reflection on national energy security *sensu largo*, but above all reflection on coal management and possibilities for substitution of coal as an energy carrier in the UK (Jevons, 1865; see also: Missemer, 2012, pp. 97–103).

It is also worth mentioning contemporary comparative analyses covering the long-duration perspective in the energy transition in European countries, conducted by P. Malanima. Such an analysis can be exemplified with a text entitled *Energy consumption in England and Italy, 1560–1913. Two pathways toward energy transition*, in which P. Malanima presents a comparative analysis of energy transitions in Italy and England over a period of several centuries. The author's comparative analysis draws on data on energy consumption, energy services, energy efficiency and energy use by society. Unlike many analyses concerned with the period of industrialization, the author does not focus on causes of energy transitions, but on their consequences for both the countries, e.g. impact on economic growth, efficiency of the economy, labor efficiency and wage growth (Malanima, 2016, pp. 78–103; see also: Federico, Malanima, 2004, pp. 437–464).

A large number of analyses, linked with energy processes and changes, is related to various theoretical inclinations evinced by researchers. The analyses include works inspired by Schumpeterian and Marxist findings, as well as works drawing on systemic approaches, anthropological and multi-aspect perspectives. Along with the development of the studies of energy transitions, research began to include more and more theoretical applications, or own ones were developed. Certainly, particular attention should be paid to studies of knowledge, technology and innovations, both from the social and technical perspective.

The most influential groups of theories, implemented by researchers to the issues of energy processes and changes, includes manifold theories concerned with innovation diffusion (Cherp, et al., 2018, pp. 175–190). These encompass theories drawing on or continuing the work of J.A. Schumpeter. An example of application of the innovation theory in the studies of novel energy technologies is a text by S. Jacobsson and A. Johnson entitled *The diffusion of renewable energy technology: an analytical framework and key issues for research* (Jacobsson, Johnson, 2000, pp. 625–640). The analysis included in the text shows that the development of wind energy generation which took place in the 1990s was an effect of technological innovation, which in turn is possible thanks to social or institutional support. Hence, it is important to prepare institutions (in respect of funding, legislation, etc.) so that they do not hamper development of a new energy technology system. According to A. Cherp and his colleagues, S. Jacobsson and A. Johnson's approach merits attention, because it combines studies of innovation systems with studies of technological systems, providing a synthetic perspective termed a concept of Technological Innovation Systems (TIS) (Cherp, et al., 2018, pp. 175–190). It appears, however, that an attempt at combining these two kinds of studies took place earlier as part of the whole neo-Schumpeterian movement, and in a sense constitutes its essence (Cf. Freeman, 1995, pp. 4–25). In the context of energy processes and changes, the concept of TIS was further developed by S. Jacobsson along with A. Bergek, B. Carlsson, S. Lindmark and A. Rickne, as well as with I. Miremadi and Y. Saboohi (Jacobsson, Bergek, 2004, pp. 815–849; Bergek, et al., 2006, pp. 1–46; Miremadi, Saboohi, Jacobsson, 2018, pp. 159–176).

In a text entitled *Assessing the performance of energy innovation systems: Towards an established set of indicators*, I. Miremadi, Y. Saboohi and S. Jacobsson employ TIS to analyze Energy Innovation Systems (EIS), that is a special kind of innovation systems (Miremadi, Saboohi, Jacobsson, 2018, pp. 159–176). For the authors, EIS is an answer to the challenges that man is faced with as regards the exploitation of the natural environment and climate change, as well as maintenance of economic growth. In order to create a practical tool for making political decisions to support and stimulate innovative action in the energy generation sector, it is essential to properly define innovation indexes. A large number of innovation indexes employed in the analysis of individual countries may demonstrate specific features of their energy innovation systems. Hence, individual countries may differ in public budget outlay on R&D

in the field of energy, distribution of funds earmarked for R&D in the sphere of energy (types of energy technologies), scientific works on innovative energy technologies, patents, installed capacity in individual energy technologies, export of energy technologies, employment rate in individual energy sectors and emissions of the national installed capacity.

Another group of theories employed to analyze energy processes and changes was presented by the so-called “Dutch school,” which established itself in the 1990s (Cherp, et al., 2018, pp. 175–190). The approaches embraced by the school were chiefly related to science and engineering, but within it one can point to various elements in the analysis, which results from extensive output of the studies on knowledge and technology. Some of the research directions were already presented while analyzing theoretical aspects of techno-economic and energy paradigms. At this point it is worth mentioning such approaches as TA, SCOT, CTA, ANT and STS. In the course of polemics with these trends and of borrowings, a concept of MLP was devised; F.W. Geels is one of its representatives. F.W. Geels’ concept would continue developing on account of the necessity to reject the accusations with regard to the slight methodological sophistication and little explicatory capacity. Still, the fact remains that the MLP approach became one of the most recognizable ones within the framework of social studies of energy systems, processes and changes (Cf. Rip, Kemp, 1998, pp. 327–399; Geels, 2002, pp. 1257–1274; Smith, Voß, Grin, 2010, pp. 435–448).

A. Cherp and his colleagues note that social approaches to energy processes and changes often did not take into consideration the achievements in the field of economics (Cherp, et al., 2018, pp. 175–190). However, it is noteworthy that in spite of all, social approaches refer to studies of innovation, which in turn are often based on achievements in the field of Schumpeterian and neo-Schumpeterian economics. A position that consolidates the issues of transition and various economic movements is encapsulated in the publications by M. Grubb, which present three spheres of transition, that is a behavioral, evolutionary and neo-evolutionary (institutional) one (Cf. Grubb, Hourcade, Neuhoff, 2015, pp. 290–302). At this point it is also noteworthy that despite the synthetic approach to the issues concerned with processes and changes in political systems on the grounds of political sciences presented in this work, it is difficult to point to research papers consolidating political science knowledge and studies of energy transition and transformation. This statement should not be identified with a lack of analyses of the politico-institutional and ideological factors affecting formation of directions of change in the energy industry. This situation might seem at least strange, especially if the literature still stresses the necessity to take into consideration political factors, and the publication by J. Meadowcroft entitled *Engaging with the politics of sustainability transitions* is regarded as a text of great relevance (Meadowcroft, 2011, pp. 70–75).

As the concept of MLP grew in strength, attempts were made to integrate the results of the research into energy processes and changes. The following texts serve as examples of integrating as well as overview-inclined approaches: "*From sectoral systems of innovation to socio-technical systems Insights about dynamics and change from sociology and institutional theory*" – F.W. Geels; "*Typology of sociotechnical transition pathways*" – F.W. Geels and J. Schot; "*Technological innovation systems and the multi-level perspective: Towards an integrated framework*" – J. Markard and B. Truffer; "*Innovation studies and sustainability transitions: the allure of the multi-level perspective and its challenges*" – A. Smith, J.-P. Voß and J. Grin; "*Energy transitions research: Insights and cautionary tales*" – A. Grübler; "*How long will it take? Conceptualizing the temporal dynamics of energy transitions*" – B.K. Sovacool; "*Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework*" – A. Cherp, V. Vinichenko, J. Jewell, E. Brutschin and B.K. Sovacool; "*Deep transitions: Emergence, acceleration, stabilization and directionality*" – J. Schot and L. Kanger (Geels, 2004, pp. 897–920; Geels, Schot, 2007, pp. 399–417; Markard, Truffer, 2008, pp. 596–615; Smith, Voß, Grin, 2010, pp. 435–448; Grübler, 2012, pp. 8–16; Sovacool, 2016, pp. 202–215; Cherp, et al., 2018, pp. 175–190; Schot, Kanger, 2018, pp. 1045–1059).

While analyzing individual publications, it should be pointed out that the problem concerned with consolidation of various theoretical approaches to energy transitions and transformations results not so much from extensive output as from a lack of solutions to basic theoretical and methodological problems related to processes and changes. Manifold analyses of energy processes and changes which attempt presentations of these issues or explicatory approaches do not achieve the goals that they themselves have set. This often results from the fact that they employ lavish metaphorical devices or a new kind of categorial apparatus, like in the case of MLP, but they do not elucidate anything that has not already been known as part of research concerned with, say, substitution of carriers or energy technologies.

An attempt at consolidating the discussion of various planes of energy transition was made by A. Cherp together with V. Vivichenko, J. Jewell, E. Brutschin and B.K. Sovacool. These authors took into consideration three kinds of changes in their analysis: (1) energy transfer in the energy production and consumption system, (2) use of technology in energy production (material mining, energy conversion and use), (3) decision-making processes in politics. Individual changes were linked with three kinds of systems: (1) a techno-economic system, (2) a socio-economic system, (3) a political system (Cherp, et al., 2018, pp. 175–190). In their approach, the authors used the legacy of the studies on systems, co-evolutionary systems and political systems. The latter one of the enumerated cases used the whole of D. Easton's output and the assumption that a mechanism of interest groups' and other entities' claims as well as the mechanism of feedback between these entities and politicians is an important aspect of the political system (Cf. Easton, 1965).

On account of the presentation of the three kinds of processes as related to the three kinds of systems, A. Cherp and his colleagues adopted three presuppositions. The first one is a statement whereby the link between the systems is co-evolutionary in the sense that a particular kind of elements can be singled out. For instance, the important elements in the socio-technical system will be energy resources and resources of other kinds, while in the socio-economic system these will include entities in the energy market, energy practices and patent practices; in the political system these will include practices of interest articulation as well as of political decisions and action, as manners of implementation of the voiced claims. Despite pointing to the elements essential for the individual three systems, A. Cherp and his colleagues assumed that they might be parts of other systems. For instance, operation of a coal-fired power plant can be regarded as practices of energy conversion and use, dominance of energy technologies, and as action of political actors, including interest groups connected with the coal industry (Cherp, et al., 2018, pp. 178–179). Another assumption is the claim that each one of the distinguished systems has capacity for autonomous evolution independently of the other systems. For instance, introducing the CSS technology may affect the persistence of the coal technology, irrespective of political claims for reducing CO_2 emissions and decreasing the significance of traditional energy carriers. By the same token, and in a different situation, when the change in the energy transfer will be determined by the diminishing coal reserves or the end of the exploitation of the old energy infrastructure, this will not, however, be caused by a shift in the political system. A third assumption is the claim that despite the possibility of singling out a special kind of elements in the three systems, and the capacity for autonomous evolution of the systems, the systems can affect one another (*Ibidem*, p. 179). For instance, changes in the political directions may affect changes in the use of new kinds of resources or energy technologies. For this purpose, a political system may use both financial and ideological instruments. Objective reasons concerned with geopolitical constraints with regard to the use of the resources or the energy infrastructure may affect the action in the political system.

Pointing to the three main systems also results in a presentation of the three main theoretical trends. The first one is a techno-economic trend; the second one is a socio-economic trend, and the third one is a political trend. The enumerated trends in the research into energy processes and changes were connected by A. Cherp and his colleagues with specific scientific disciplines. The aesthetics of this methodological solution is reminiscent of A. Cherp's and J. Jewell's earlier works which addressed the issues of energy security (See Cherp, Jewell, 2011, pp. 202–212). The techno-economic trend was able to develop thanks to the achievements in such disciplines as economic history, neoclassical economics, evolutionary economics, ecological economics and studies of energy systems. The socio-technical trend is associated with the achievements of such disciplines as sociology and history of technology, evolutionary economics and STS. The trend of political studies of transitions is based on the achievements of political sciences, international relations and political economy. It is also noteworthy that B.K. Sovacool, in an earlier text and regardless of the stance presented together with A. Cherp's research team, singled out four other theoretical approaches, in which he included a socio-technical approach, an approach of ecological modernization, an approach based on sociology and social practices, an approach of political ecology (Sovacool, 2016, p. 206). Compared with an earlier text by B.K. Sovacool, the division presented by A. Cherp and his colleagues constitutes a more synthetic and universal proposal with regard to the typology of trends addressing the issues of energy transitions. A limited number of theoretical approaches in general, recognized within the two above-mentioned typologies may result in an excessive trivialization of the discourse engaged in as part of the studies of energy processes and changes; also, it may not point to the real links of interdependence between individual concepts or their representatives. Still, it must be concluded that the typologies presented by B.K. Sovacool himself and A. Cherp and his colleagues constitute a well-thought-out solution facilitating insight into the studies of energy transitions.

Drawing on specific achievements of the disciplines within the individual trends results in adaptation or creative elaboration of the models and theories. In the case of the techno-economic trend use was made of integrated asset modelling (IAM) and scenario methods. In the socio-technical trend, transition management and an innovation policy were employed. The political trend employed designing of international regimes and public policies.

In the techno-economic approach to transitions, emphasis is laid on the processes of energy conversion within the market. The processes of energy conversion are construed relatively broadly, as they comprise material extraction, energy production, energy transformation, energy transmission and the services of energy end use. Most often, these issues are reduced to three kinds, that is production, consumption of and dealing in energy. Considering the third issue results in economic orientation in the studies of energy transitions, because the relation between supply and demand factors is essential. All the analyses concerned with the costs of the carriers and energy technologies should be placed within the same approach. Stressing the significance of the technical aspect of transitions links the trend with such disciplines as life and technical sciences. Therefore, techno-economic approaches often draw on quantitative analyses, which also favors a presentation of quantitative models of energy systems and long-term scenarios for energy industry development (Cherp, et al., 2018, pp. 179–180).

In the socio-technical approach to transitions emphasis is laid on technological processes and changes with particular reference to diffusion of innovations. In a broad scope, this trend draws on the scientific achievements of the studies of innovation as part of both evolutionary economics and STS. As part of the socio-technical approach a particular group is constituted by MLP representatives, e.g. F.W. Geels and J. Schot. The roots of the discipline also include sociology and history of technology, in which particular emphasis was placed on analyses covering long time-frames. In comparison with the previous theoretical approach, which reduced technology to energy conversion mechanisms, the socio-technical approach treats technology as a social phenomenon and sets it within a wider scope of interaction between social entities. Systems of innovation and interdependence between the core and periphery areas in the context of the diffusion of substitution of carriers or energy technologies also fall within the compass of analysis. The main subjects addressed in the studies include transition trajectories, items essential for energy substitutions, the so-called "path dependence," dependence on conventional energy carriers, dependence on specific technologies. As part of this approach, individual researchers may differently highlight an analysis of energy transitions, e.g. some will emphasize systems of innovation as parts of the technological or socio-technological regime (e.g. TIS), while others will highlight multi-level relationships which result from the adaptation of the analysis of the achievements of systemic approaches, evolutionary economics, sociology and history (e.g. MLP) to the models. Apart from this bipolar division, typical studies which segment complex reality into various kinds of systems – e.g. sectoral systems or individual technological systems – can be distinguished (Sovacool, 2016, pp. 205–207; Cherp, et al., 2018, pp. 180–181).

In the political approach to transitions emphasis is laid on political action, political solutions in the field of energy generation and institutional interrelationships within the energy industry (Cherp, et al., 2018, pp. 181–183). At least two directions of analysis may be pointed to, the first one being an institutional approach emphasizing the significance of public policies, and the second one – a broader approach to political entities as social actors constituting one of the factors of influence within the network of connections (ANT). However, the effect of the considerable attachment to the systemic approaches is that the political approaches to transitions draw on the view of a policy which no longer is influential in political sciences, that is D. Easton's systemic approach (Easton, 1965; Laska, Nocoń, 2010, pp. 155–164). The effect of the references made to the view of the political system is the adaptation of the inter-systemic analysis to political processes with regard to the energy industry – mechanisms of social demands as well as mechanisms of political action and decisions as a response to social demands. A major role in the political analysis is also played by political interests, interest groups, voters' preferences and acceptance of political projects in the sphere of the energy industry by voters. Next to postmodernist concepts in political sciences, the political approaches to energy transitions witnessed the emergence of a problem concerned with the extent to which a state constitutes an autonomous entity capable of action and decision-making in the energy sector. The problem of decision-making autonomy – and more broadly, state sovereignty – takes on special meaning in the context of the potential of energy companies as part of globalization processes (Cf. Hall, 1993, pp. 275–296; Beck, 2005; Meadowcroft, 2011, pp. 70–75; Geels, 2014, pp. 21–40; Avelino, Grin, Pel, Jhagroe, 2016, pp. 557–567; Avelino, 2017, pp. 505–520; Cherp, et al., 2018, pp. 181–183). Besides, with regard to the concept of the diffusion of innovations – within the compass of energy generation – some researchers attempt to analyze politics alone and political ideas in a manner analogous to innovations or call for such a research direction (Sovacool, 2016, pp. 202–212).

The political trend should also include some directions related to TA (e.g. CTA, DTA, PTA, pTA). However, the whole of TA performs a cautionary and informative function with regard to technologies for social and political entities. Along with the development of new technologies, the cautionary function came to be supported by a function that raises awareness of both the risks concerned with the development of individual technologies, including energy-related ones, as well as of the essence and significance of specific technologies. TA does not focus on history, but on the future, and therefore it performs forecasting functions, and thus can affect future social and political choices concerned with trajectories of the development of energy technologies. The relationship between TA and the issues of transition concerns future scenarios for the development of energy technologies. However, TA comes up against two problems concerned with the implementation of its functions. The first problem is the fact that it is relatively difficult to assess future effects of the implementation and development of specific trajectories of energy technologies. The second problem is that when at last the establishment of a specific trajectory of an energy technology takes place, it is relatively difficult to change it. Also, D. Collingridge found that whenever a technological change is easy, it cannot be predicted; and conversely, when the need for a change is obvious, a technological change becomes costly, difficult and time-consuming (Collingridge, 1980; Liebert, Schmidt, 2010, pp. 55–71; Wagner-Döbler, 1989; Schot, Rip, 1997, pp. 251–268; Joss, Bellucci, et al., 2002).

In TA technology assessments, which constitute a form of social or political cost benefit analysis, are difficult to make; at times they are impossible to make in an objective manner at all. In public debate an important role will therefore be played by independent experts, exploited by politicians to justify their action and decisions. However, experts, who are supposed to be arbitrators in a debate, will often be perceived as a party to the conflict. In consequence, experts who do not remain impartial in the dispute over the assessment or choice of a trajectory of the development of an energy technology, will too become social entities entangled in the network of interrelationships. In spite of all, political and institutional mechanisms for verification of technologies must be created, because in TA it is essential that the technologies which we can properly control are developed (Cf. Collingridge, 1980, p. 161). In assessing energy technologies, it is impossible to avoid argumentation based on socially accepted values; what is more, while making such an assessment, one can also design values, because choosing a proper technology also means choosing a specific idea. At this point it is noteworthy that in the proposed typology of theoretical trends of energy transitions, the importance of ethical aspects is frequently minimized; they are most often emphasized in the context of the discussion about sustainable transitions or sustainable development in the energy industry.

As a consequence of the singling out of the three theoretical trends in the studies of energy processes and changes A. Cherp and his colleagues proposed a synthetic meta-theoretical framework which will also constitute a more effective tool for analysis of national energy transitions. Each one of the trends has been ascribed to the three kinds of main variables, which in turn were even more specified with the second-order variables. The main variables for the techno-economic system are resources, demand and infrastructure, while the main variables for the socio-economic system are innovation systems, regimes and niches, as well as processes of technology diffusion. The main variables for the political system are state goals and political interests, as well as institutions and possibilities/potential (Cherp, et al., 2018, pp. 185–187).

By referring to one of the examples provided by the authors, the usefulness of the meta-theoretical framework in the interpretation of the course of national transitions can be presented. For instance, changes in the energy industry in Germany in the 1970s and 1980s were caused by political and techno-economic factors. A substantial demand for energy was translated into efforts to decrease energy-intensity, and stimulated investment in the nuclear energy sector. At the same time, research was conducted into alternative energy sources and RES. Apart from the demand factor an important role was played by a political factor related to an external threat, that is a lack of supply of resources during the first oil crisis. The goal set by the state was to assure state security by providing uninterrupted supply of resources and electricity. At the beginning of the 1990s Germany's economic situation changed; the demand for electricity was not as dynamic as before. The result of the situation was lower demand for expansion of new capacities in the nuclear sector, which in a sense slightly impaired the socio-technical regime. Furthermore, successive trajectories of energy development in Germany were opened; having greater energy security than Japan, Germany began exploiting ever greater RES reserves as of the 1990s. In addition, Germany did an about-face in the nuclear sector, that is it cut down on its commitment, unlike Japan. Explanations for these shifts can be found in the socio-technical approach, which points out that the wind technology was brought over from Denmark at the beginning of the 1990s. The conditions conducive to this were similar socio-geographic determinants and a moderately favorable legal and institutional environment in Germany and Denmark. Another stage consisted in further elimination of nuclear energy generation, which was related to political factors in the form of political interests of the ruling parties, in this case the Green Party and the SPD. In Japan, such a change was impossible, because this country did not implement wind technology in the extent in which Germany did it (*Ibidem*, pp. 185–187). Apparently, the interpretation of energy processes and changes in Germany with the of aid of the meta-theoretical framework was presented by the authors in a too concise manner; however, the point of the text was to present the current state of research, its integration and presentation of the meta-theoretical framework of energy transitions.

2.4. Substitution of energy and energy technologies

B.K. Sovacool points out that it is difficult to present in the scientific literature a widely accepted definition of an energy transition. And yet, one of the major motifs in the content of the definition of transition is a shift from one energy carrier to another one, or a shift from one energy technology to another one (Sovacool, 2016, pp. 202–215; See also: Fouquet, Pearson, 2012, pp. 1–7). A narrow understanding of transition focuses only on shifts between major energy carriers, that is wood, coal, oil and gas. More often than not, such approaches do not, however, include an analysis of social and cultural determinants of shifts; nor do they take into consideration the role of socio-political actors who play a major role in the choice of the directions of change. In the case of a broad understanding of transition, efforts are made to set the trajectory of change in the energy industry within the framework of multi-dimensional social, political and cultural relationships. The degree of change intensity in the energy industry, as well as the period of this kind of change, remain an unsolved problem, which yet is an object of analysis. For instance, V. Smil points out that an energy transition is a period of time that elapses between an introduction of a new carrier of primary energy and an increase in its significance in the energy structure (Smil, 2010a, pp. 136–141). Still, it is noteworthy that between the former and the latter points many variables may be at play; these might significantly affect the time of adaptation of a given carrier, which in turn may be of relevance in a situation where we draw conclusions from the emergent differences. The threshold of adaptation and dominance of a carrier or an energy technology will be another problem concerned with an energy transition thus specified. For instance, V. Smil locates the threshold at a 25% carrier share in the national or global energy structure. Other authors, e.g. A. Grübler, point out that a carrier's share in the structure of demand for energy of at least 50% marks the threshold (Grübler, et al., 2012, pp. 1665–1744). Therefore, the considerable discrepancies in both the quantitative and qualitative assessment of the adaptation and dominance of carriers and energy technologies can clearly be seen. However, it appears that defining the threshold of share so accurately may fail, because if the energy structure remains diversified for a long period of time, then there will be no spectacular transitions, even though replacement of individual carriers in the energy structure will still be possible.

The turning point for energy substitution and energy technology is not the only problem encountered in analyses of energy transitions. Researchers of these issues draw attention to at least two factors, i.e. a technological and an institutional one (including an organizational one). There is no doubt that the enumerated factors considerably account for the dynamics of historical energy transitions. One of the most important mechanisms is feedback, which takes place between the technology of energy conversion and development of successive sectors, which drive demand for a given kind of energy. For instance, the advent of the combustion engine served to consolidate the development of transport, which in turn helped develop the petroleum and petroleum products industry.

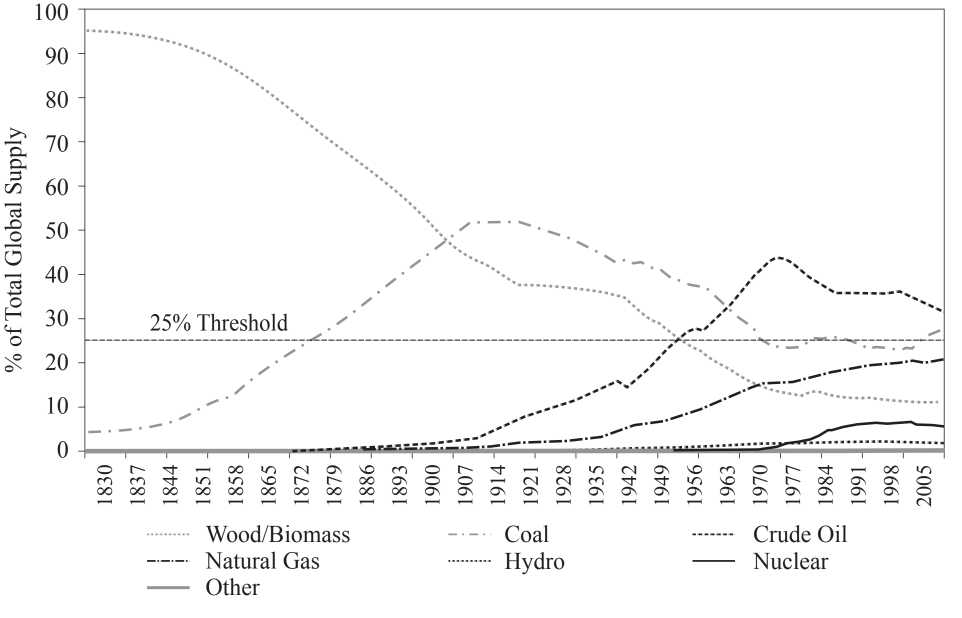
A. Grübler claims that both demand and supply factors are of significance. Demand for energy and energy supply systems co-evolve, which comes to be reflected in mutually reinforcing innovations in both the spheres. A. Grübler cites research which stresses that the level of investment in the end use of energy is higher than the investment level in energy supply sector. Investment of this kind should be treated as a mechanism of rise and exchange of sector share capital. This shows that the share capital of the energy sector is much bigger on the part of energy end users than on the supply side (Grübler, 2012, pp. 8–16).

Even if we limit the energy transition approach to the substitution of energy carriers or technologies, the main two problems that will remain are determinants of change and the time-frame of change. As regards the time-frame, identification of the turning point for substitution of carriers or technologies is also significant. It was earlier on – at the time of the analysis of the main concepts of energy processes and changes – that research by A. Grübler and V. Smil was presented. For instance, V. Smil finds the attainment of a 25% share of a specific carrier in the energy structure to be a turning point, while for A. Grübler the turning point is marked at a 50% share. For N. Nakićenović attainment of a sufficient share in the market will be of significance, but it must be noted that the share will depend on the specificity of carriers and technologies. Of a similar opinion is M. Melosi, who in his writing assumes that an energy transition is based on the presupposition of a dominance of one or several energy carriers in a specific period of time, and then on their substitution (Melosi, 2010, pp. 45–60). There is no doubt that according to C. Marchetti and N. Nakićenović it is possible to point to time constants of change in substitution as well as periods of market saturation.

S. Lacey, while quoting V. Smil, points out that it takes between 50 and 70 years for a specific energy carrier to penetrate the market, which proves that despite the outlay, proper regulations in force, etc., decades pass before any energy carrier can materially affect the energy structure (Lacey, 2010). Like V. Smil, B.K. Sovacool pointed out that petroleum took more than 50 years to transition from research work to a 10% share in the US market, which took place between the 1860s and the 1920s. Another three decades were needed for petroleum to gain a 25% share in the US market. By contrast, natural gas took 70 years to gain a 20% market share, while coal took 103 years to gain a 5% share in the total energy consumption in the USA, and another 26 years to reach a 25% share in the total consumption. The nuclear technology was characterized by a shorter period of transition, as it took 38 years for electricity generated at nuclear power plants to gain a 20% share in the US market in the 1990s (Smil, 2012, pp. 46–52; Sovacool, 2016, p. 205).

B.K. Sovacool notes that the global perspective displays much longer transition periods; for instance, coal reached a 25% level in the global energy structure at the beginning of the 1870s, that is after more than 500 years, if we set the starting point at the time of the first commercial coal mines in England (Sovacool, 2016, pp. 205–207). For instance, according to data by E.A. Wrigley, as for the energy supply level in England and Wales, coal gained a 30% share in the 17th century, and almost a 50% share as early as the beginning of the 18th century (See Figure 4) (Wrigley, 2013).

Figure 4. Global structure of energy supply by energy source in the years 1830–2010 (as a % share)



The "wood-biomass" carrier also includes biofuels, while "other" includes renewable energy sources such as wind, solar and geothermal energy.

Source: Sovacool, 2016 (See also data: Smil, 2010b; IEA).

In the case of petroleum, on a global scale, this carrier exceeded the 25% level in 1953, which amounts to more than 90 years, if we consider the start of the operation of the first oil rig in Pennsylvania by E.L. Drake. Certainly, other starting dates can be pointed to, e.g. the first commercial oil rig dates back to 1859, F.N. Semyenov's oil well in the Absheron Peninsula in Azerbaijan dates back to 1848, S. Jabłonowski's oil well near Gorlice in Poland dates back to 1852, I. Łukasiewicz's oil well in the Subcarpathian Province in Poland dates back to 1854. However, it must be borne in mind that extraction of petroleum alone would not have become that relevant if it had not been for innovations concerned with its distillation, which was in fact the change that increased interest in petroleum in the 19th century (Mierzecki, 1999, pp. 56–69; Graniczny, Wołkowicz, Urban, et al., 2015, pp. 151–156; Sovacool, 2016, pp. 205–207; Lorenz, Szwed-Lorenz, Ślusarczyk, 2017, pp. 201−207).

Measurement of transitions may pose problems because of the quantitative and qualitative assessment of change. This results from the fact that a given energy system or a technology will develop rapidly in absolute terms, but not from a comparative perspective. For instance, hydropower in the USA in the 1950s and 1960s was a low-cost source of energy, the installed capacity of which increased threefold. However, it should be noted that at the same time the USA witnessed an increase in demand for electricity, while hydropower's share dropped from 32% to 16% (Sovacool, 2016, p. 203). Besides, it is often necessary to analyze a larger number of energy systems and technologies, as better identification of a transition requires taking into consideration a larger number of processes and changes as well as their mutual connections. Development trajectories of rail and road transport, of a transport technology and a resource transport technology may serve here as an example of this kind of changes and connections (Grübler, 1996, pp. 19–42).

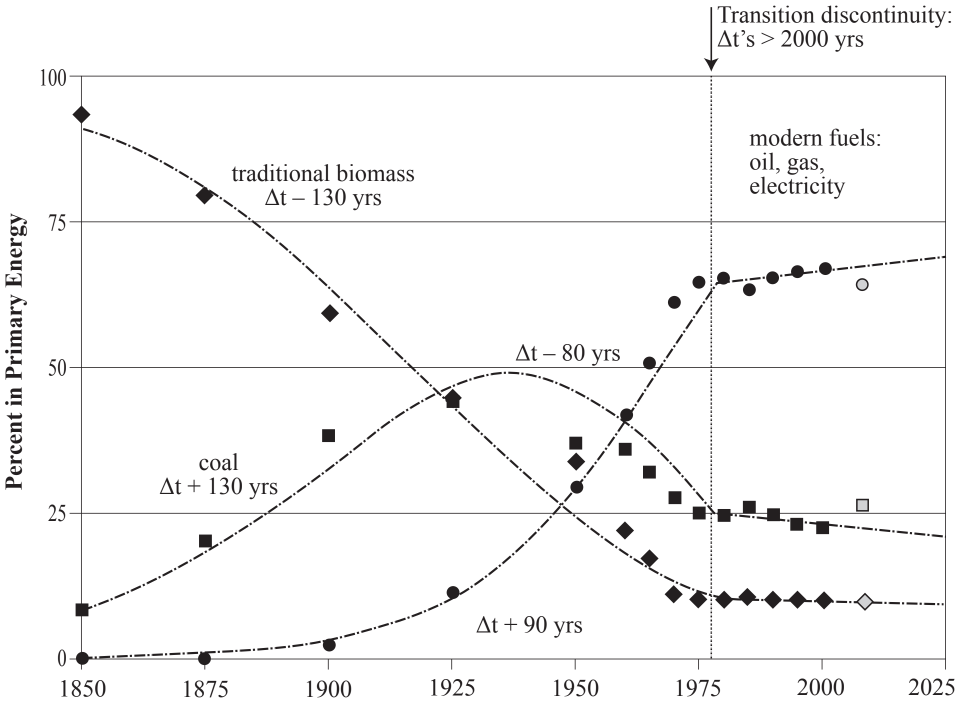
A. Grübler proposed a summary of all the energy transitions that took place in Europe between 1800 and 2000. The author's synthetic approach also considers the diffusion processes of energy technologies between the core and the periphery. A. Grübler's model of transition was based on a single aggregated indicator, that is a fractional share of coal in the respective primary energy balance. In the energy transition in individual European countries, the rise of coal in a sense mirrors a shift from the pre-industrial to industrial system. The decline of coal in the industrial system points to the rise of end-use energy technology (Grübler, 2012, pp. 8–16).

2.5. Pace of the substitution of energy and energy technologies

According to A. Grübler energy transitions in Europe were varied in respect of their time-frames (See Figure 5). Hence, two main energy transitions may be pointed out. The first one was related to the shift from pre-industrial energy sources to coal, while the second one was related to the shift from coal to successive energy sources. The energy processes and changes presented by A. Grübler display a delay of almost two centuries. The time perspective is also mirrored in the spatial diffusion of carrier or technology substitution, which takes place between core and periphery countries. As regards coal substitution, the diffusion progresses from core to periphery countries. Substitutions of energy carriers and technologies would pass from core countries, which initiated innovation, through rim countries, adopting innovation early, to periphery countries, which adopted innovation the latest.

However, it is noteworthy that core countries are characterized by long-lasting and slow transition, while periphery countries are characterized by relatively short-lived and quick transitions (See Table 1). Interestingly enough, the diffusion of the substitution of energy carriers and technologies that progresses from core countries to periphery countries will be reversed along with the passage between the first and second energy transition – that is between the coal- and steam-based transition and the transition consisting in a departure from the inefficient coal and steam technology (Grübler, 2012, pp. 8–16; Sovacool, 2016, p. 204).

Figure 5. Transitions in the global use of primary energy 1850–2008



The lines are model estimates using a multiple logistic substitution model to approximate the historical data.

Source: Grübler, 2012, p. 12.

In the case of the analysis concerned with the two transitions, A. Grübler points out, citing research by, inter alia, C. Marchetti and N. Nakićenović, that on the global scale, a typical period of a transition of a primary energy structure lasts between 80 and 130 years. In the case of the lower time limit, the period of change concerned substitutions of oil, gas and electricity, while the upper time limit referred to the period of change concerned with substitutions of steam energy for pre-industrial energy sources (Marchetti, Nakićenović, 1979, pp. 1–69; Grübler, 2012, pp. 8–16).

Table 1

Differences in the time and pace of energy transitions in Europe

		Diffusion midpoint T_0	Diffusion speed Δt
PHASE-OUT OF TRADITIONAL RENEWABLES PHASE-IN OF COAL:			
Core	England	1736	160
Rim	Germany	1857	102
	France	1870	107
	Netherlands	1873	105
Periphery	Spain	1919	111
	Sweden	1922	96
	Italy	1919	98
	Portugal	1949	135
PHASE-OUT OF COAL PHASE-IN OF OIL/GAS/ELECTRICITY			
Core	Portugal	1966	47
	Italy	1960	65
	Sweden	1963	67
Rim	Spain	1975	69
	Netherlands	1962	62
	France	1972	65
Periphery	Germany	1984	50
	England	1979	67

Source: Grübler, 2012, p. 13.

According to A. Grübler's analyses, the first transition, that is the one concerned with the progress from the pre-industrial system to the industrial one, was to a considerable degree delayed. The period between 1736 (England and Wales as core countries) and 1949 (Portugal as a periphery country) saw a phase-out of pre-industrial energy carriers – biomass and renewable energy sources. The transition from pre-industrial energy carriers to coal, as part of the spatial division into cores, rims and peripheries, lasted between 46 and 160 years. The transition from coal to oil and electricity lasted between 47 and 69 years. The 'periphery' countries in the spatial diffusion of coal become the first ones to begin using post-coal technologies. By contrast, pioneers of coal technologies introduce new technologies with approximately 20 years' delay; furthermore, in the group of these countries, technology diffusion is slower within the second energy transition. At the same time, it is noteworthy that the pace of the second energy transition is higher, which can be related to a greater potential of the comparative advantage of coal substitutes (Grübler, 2012, pp. 8–16). Consequently, core countries, which introduce innovations, maintain unattractive and less competitive technologies, because they need more time for change. Sometimes core countries overinvest in technologies, which results in the fact that it is more difficult for them to give up those technologies (Sovacool, 2016, p. 204). The conclusions concerned with A. Grübler's research, which can be used for forecasting purposes show that the current 'periphery' countries will be the pioneers of another energy transition. Similar presuppositions were also presented by A. Grübler together with A. Nakićenović and A. McDonald in a publication entitled *Global Energy Perspectives* (Nakićenović, Grübler, McDonald, 1998). In addition, it may be assumed that to a great degree 'core' countries will be dependent on fossil energy carriers, while quicker changes are to be expected in such countries as China and India.

Apart from pointing to two significant transitions, A. Grübler noted that as of the mid-1970s there was a slowdown in the pace of change, which resulted in the establishment of an unfavorable starting point for a potential successive energy transition. It is hard to unambiguously point to the reasons for the slow pace of change. The global scale of energy markets may be one of the reasons. This would mean that the size of the system – in this case an energy system – gives rise to its lesser susceptibility to external stimuli coming from technological niches. Still, this does not mean that at that time parallel energy technologies are not developing. In the first place, these technologies may constitute test trajectories, making for potential for a future energy substitution. This results from the fact that it is easier to replace one technological regime with another one than to create a new one from scratch. Of great significance may also be an economic factor, within which included should be a comparative advantage with regard to electricity. According to A. Grübler a comparative advantage had greater potential in the case of the end use of electricity than in the case of the energy supply technology (Grübler, 2012, pp. 8–16). This presupposition may be proven with the aid of the price analyses by, inter alia, R. Fouquet; these point out that the prices of energy services fell more rapidly and drastically than energy prices (Fouquet, Pearson, 2003, pp. 93–110; Fouquet, Pearson, 2006, pp. 139–177; Fouquet, 2011a, pp. 196–218). This also has its implications in the form of more rapid transitions in the sphere of the technology of energy end use, as well as it may give rise to substantial redefinition of political strategies in the energy industry.

The above-quoted literature often presupposes the proposition whereby energy transitions take a long period of time. In the conclusion to the final chapter of his book entitled *Energy Transitions: History, Requirements, Prospects* V. Smil states that a long period is a feature of a transition, and – what is more – it will be longer in societies in which energy consumption is very high (Smil, 2010b, pp. 142–153). A large amount of generated energy is related to a dominance of a specific kind of technology, and its costs constitute a factor delaying a substitution of new energy carriers and technologies. This is pointed out by analyses by A. Grübler, J. Schot, B.K. Sovacool, N. Nakićenović and many others. These propositions are accepted for substitutions of both energy carriers and individual energy technologies. The latter case came to be corroborated by, inter alia, research papers by R. Fouquet and P.J.G. Pearson with regard to transitions of energy carriers and services between the 16th and 20th centuries. It follows from these authors' studies that each one of the transitions underwent an innovation stage which lasted more than one hundred years, and then came another stage encompassing diffusion processes lasting almost fifty years. This in turn means that complete transitions are a rarity on account of the time needed for them to become realized (Cf. Fouquet, Pearson, 2003, pp. 93–110; Fouquet, Pearson, 2006, pp. 139–177; Fouquet, Pearson, 2012, pp. 1–7; Fouquet, 2008; Fouquet, 2011b, pp. 4–12; Fouquet, 2014, pp. 186–207; Fouquet, 2015, pp. 147–156). One might conclude that the assumptions about the length of energy transitions are close to analyses of innovation diffusion in technologies of propelling mechanisms. Short periods do occur, but they are often related to end technologies of fuel use, and not to whole technological regimes (Sovacool, 2016, pp. 206–207). Therefore, it seems unreal that a global, structured energy paradigm will change, even within half a century. The text by R. Fouquet and P.J.G. Pearson, who summarize other research into energy processes and changes, presents a proposition concerned with a dozen or so transitions that have been studied, which posits that an energy transition takes at least forty years to become fact. A minimum period of forty years is necessary for progress from the innovation stage, through a stage of technological niche development, and to a stage of dominance within individual systems. However, this period did not concern the whole technological regime, because its change may last longer than one hundred years (Fouquet, Pearson, 2012, p. 2).

B.K. Sovacool emphasizes that despite the widely accepted propositions about the time-intensiveness of a transition, there are also some premises upon which to posit that processes and changes of this kind may take place relatively rapidly. The author presents three arguments for such a stance. The first one is an empirically proven fact of relatively rapid transitions within the scope of end technologies of energy use and driving mechanisms. The second argument is an empirically proven fact of relatively rapid transitions on a national scale. The third argument is about accepting that determinants of historical transitions do not need to be identical with determinants of future energy transitions (Sovacool, 2016, p. 207). Despite varying positions with regard to dynamics, it is noteworthy that the experience gained while studying energy processes and changes may be employed for a more effective development of the decision-making process, e.g. within individual public policies.

Apart from the argumentation for the acceptance of the possibility of emergence of changes and processes over long periods, B.K. Sovacool presented several examples of – as he himself termed them – “rapid transitions” (See Table 2). As regards the current member states of the European Union, it is worth drawing attention to Denmark, France, the Netherlands and Sweden. According to B.K. Sovacool, the revolutions in the above-listed countries lasted between three and eleven years, and it might seem that they were concerned with innovations that did not change the whole socio-technological regime, but only affected the workings of individual systems (*Ibidem*, pp. 207–210). The shortest transition, within a group of European countries, involved a process concerned with the introduction of a combined heat and power technology, which directly affected the supply of electricity and heating to consumers in Denmark. At the same time there was a shift from an oil-based energy generation to a coal-based one. All these changes took place against the backdrop of the threat that was revealed by the first oil crisis at the beginning of the 1970s. By contrast, the longest transition, within a group of European countries, involved a substitution of energy carriers and an energy technology in France. With regard to both the cases of Denmark and France, one might ask oneself whether it was only about a transition of a systemic range, or whether it was a process of formation of a new national socio-technological regime. There appears to have been a whole transition of a technological regime with regard to a substitution of carriers and an energy technology. A threat to energy security caused by the first oil crisis was the direct cause of the steadfast direction of change in France, just like in Denmark. Also, T. Młynarski points out that the considerable economic growth in France which lasted as of the mid-1940s (the so-called *Trente Glorieuses*) gave rise to the high level of energy dependence, and it was nuclear energy that was supposed to provide the answer to this kind of threat, in keeping with the political argument of *no oil, no gas, no coal, no choice* (Młynarski, 2013, pp. 94–96, see also: Olah, Goeppert, Prakash, 2006, pp. 119–121).

Table 2

Overview of rapid energy transitions

Country	Technology/fuel	Market or sector	Period of transition	Number of years
Sweden	Energy-efficient ballasts	Commercial buildings	1991–2000	7
China	Improved cookstoves	Rural households	1983–1998	8
Indonesia	LPG stoves	Urban and rural households	2007–2010	3
Brazil	Flex-fuel vehicles	New automobile sales	2004–2009	1
USA	Air conditioning	Urban and rural households	1947–1970	16
Kuwait	Crude oil and electricity	National energy supply	1946–1955	2
Netherlands	Natural gas	National energy supply	1959–1971	10
France	Nuclear electricity	Electricity	1974–1982	11
Denmark	Combined heat and power	Electricity and heating	1976–1981	3
Canada **(Ontario)**	Coal	Electricity	2003–2014	11

The number of years concerns a transition from a 1% to 25% market share. The Ontario (one of Canadian provinces) case displays an inverse process, i.e. a transition from a 25% to 0% coal share.

Source: Sovacool, 2016, p. 208.

On the basis of the cases under analysis, B.K. Sovacool concluded that the assumption featuring in the mainstream of the studies of energy processes and changes, whereby transitions need to last decades is at least dubious. This means that changes in the energy sector do not need to concern many generations, and so they can constitute a better-thought-out social and political projects. Subsequent energy projects must be based on three kinds of problems. The first problem is resource depletion; the second problem is climate protection; the third one is innovation (Sovacool, 2016, pp. 210–211).

B.K. Sovacool claims that the previous transitions were determined mainly by prices and energy resource availability, while the subsequent ones may be based on scarcity and inaccessibility of energy resources. The literature on energy security abounds in analyses concerned with resource depletion and "extraction peaks," particularly with regard to crude oil (Cf. Yergin, 1991; Maugeri, 2006; Tsatskin, Balaban, 2008, pp. 1826–1828; Priest, 2014, pp. 37–79). It may be noted that from the viewpoint of energy security, the problem of resource depletion concerns each energy carrier, e.g. wood, gas, uranium, etc. Frequently, statistical indices of depletion of individual energy resources – e.g. the ones presented in BP reports or other publications on the problem of energy security – are invoked here (Cf. Kałążna, Rosicki, 2010, 34–51, 69–85). Hence, energy resource extraction peaks should constitute turning points for the implementation of new energy technologies. It appears that the distinction made by B.K. Sovacool between availability and unavailability with regard to the prices is artificial. This statement follows from the fact that a lack of proper resources always channels activities towards the use of those that are available. Therefore, it may be posited that a change of outlook in future transitions towards the issues of resource unavailability does not constitute a significant revision of the action engaged in by social and political entities.

Environmental resources undergo continued exploitation, and so it must be borne in mind that the environment is not a good that can be exploited forever. One of the major problems concerned with the exploitation of energy resources is the emissions of conventional fuels. B.K. Sovacool points out that negative environmental consequences will constitute an important factor affecting rapid energy processes and changes (Sovacool, 2016, p. 210). Solid and liquid fuels used in societies which are more and more aware of environmental threats will be viewed as a challenge and a problem concerned with the use of "energy assets." As part of this special kind of portfolio, coal assets will ultimately constitute toxic assets. However, it is noteworthy that the influence of social entities on account of unexpected events such as the Three Mile Island accident (1979), the Chernobyl disaster (1986) and the Fukushima Nuclear Accident (2011) carried more weight with the decisions made by political entities. Such occurrences and activation of social entities were of great relevance for the development of nuclear energy industry, e.g. in such countries as the US, Italy, Austria and Germany (Cf. Potter, Kerner, 1988, pp. 1–27; Potter, 1990, pp. 1–85; Hassard, Swee, Ghanem, Unesaki, 2013, pp. 566–575; Iimura, Cross, 2016, pp. 518–532; Bigerna, Bollino, Polinori, 2017, pp. 345–373; Khan, 2018, pp. 116–134). The climate problem may therefore constitute a faraway idea, because it may not activate larger segments of society. In a case like this, it is important to exert influence with the aid of various political mechanisms.

There is no doubt that planned and unplanned innovations may significantly affect the course of future transitions. B.K. Sovacool drew attention to the significance of both technological innovations and "political innovations" (Sovacool, 2016, pp. 210–211). In the case of political innovations, a major role may be played by diffusions of ideas, but also new methods for making decisions. However, it appears that if no new kind of idea or new style of decision-making is accepted, it is hard to speak about the emergence of social conditions conducive to the initiation of energy transitions. By analyzing political and social factors, it is possible to point to two directions of political action. The first direction is concerned with an attempt at urging social entities to act in favor of a specific idea or political project. The second direction is concerned with top-down political action geared towards a lack of negative social activation oriented at proposed energy solutions. A lack of reaction on the part of social entities towards the imposed energy projects may result from little awareness of the energy issues, a low level of participatory culture or tacit consent to the action and decisions by political entities. In the case of the European Union and its solutions as to the energy industry, one can often see less interest on the part of social entities, and more interest in the directions of change of economic entities. This can be exemplified with the decision-making process concerned with the introduction of compact fluorescent lamps which were supposed to replace traditional light bulbs in the territory of the European Union. In sum, by analyzing texts addressing the issues of transition related to changes concerned with sustainable development, or changes concerned with the energy sector, one might conclude that they often do not consider the theoretical findings of the studies of political change, but if they do consider them, they do it in an unsatisfactory manner. It appears that the research results with regard to the studies of political change and policy-making processes should be to a greater degree implemented within a broader framework of analysis of energy transition (Cf. Meadowcroft, 2011, pp. 70–75; Avelino, Grin, Pel, Jhagroe, 2016, pp. 557–567; Kern, Rogge, 2017, pp. 102–117; Wittmayer, Avelino, van Steenbergen, Loorbach, 2017, pp. 45–56).

In analyses of the speed of transition, it is also worth considering such factors as public policy and infrastructure constraints. The significance of policy with regard to making law that facilitates innovation and engaging in economic activity concerned with energy generation seems obvious. As part of the public policy, particular attention should be drawn to financial mechanisms for supporting specific energy technologies.

Proper financial support from the public sector or the public sector guarantees issued for commercial institutions may substantially speed up processes in the energy sector. For instance, according to N. Pfund and B. Healey, inflation-adjusted federal funding for the nuclear sector in the USA accounted for 1% of the federal budget in the first fifteen years. By contrast, funding for the oil and gas sector accounted for half of the budget, while funding for renewable energy sources accounted for about 0.1% in the first fifteen years of financial support. The authors state that the federal funding for the oil and gas sector was five times higher than the one for the renewable energy sources sector, while funding for the nuclear sector was more than ten times higher – if we regard the first fifteen years of the funding for each of the sectors as the comparison period. Expressed in dollars and inflation-adjusted, the expenditure on the nuclear energy sector amounted to $3.3bn in the comparison period, on the oil and gas sector – $1.8bn, on the renewable energy sources – less than $0.4bn. The accumulated values of the funding for the oil and gas sector added up to almost $447bn (in the years 1918–2009), for the nuclear sector – more than $158bn (in the years 1947–1999), for the biofuel sector – more than $32bn (in the years 1980–2009), for the renewable energy sources sector – almost $6bn (in the years 1994–2009) (Pfund, Healey, 2011, pp. 2–37).[11] One might assume that these discrepancies will be mirrored in the period of successive transitions, and in the possible emergence of a turning point for substitution of carriers or energy technologies.

It is to be noted that also infrastructural constraints in relation to geographical aspects may substantially affect diffusions of carriers and energy technologies. In the USA, this can be exemplified with geographical disproportions in the distribution of electricity transmission networks. Their distribution is associated with the distribution of solid fuels, sources of hydropower, wind and solar resources. Preparation of new transmission networks, particularly for new technologies, or conversion of old networks on account of their maintenance poses a major challenge with regard to the public policy, especially in the context of a clash of interests represented by many actors – political, social and economic ones. A choice that considers new kinds of US energy resources, especially renewable ones, may in significant a manner affect the period of transition and a possible emergence of a turning point for a substitution of carriers and energy technologies (Cf. Doyle, 2007, pp. 624–629; *2016 Renewable Energy Data Book,* 2017, pp. 6–18; Bloom, 2018).

The studies of transition provide knowledge that can be employed to minimize unnecessary backwardness and to eliminate obstacles to a quicker pace of change in the energy sector. The effects of the new theoretical framework and empirical analyses include more effective models which point to both the causes and the course of energy transitions. Still, the studies feature problems related to: (1) a qualitative assessment of the significance of changes (e.g. new social practices, new decision-making processes and new technologies), (2) a qualitative assessment with regard to the scope of changes (social groups, nations, states, regions, etc.), (3) a qualitative assessment of the significance of the change of energy carriers and the related technologies, (4) a qualitative assessment of the relevance of the significant points for the substitution of energy carriers and technologies, (5) a qualitative assessment of the significance of the speed of changes in the energy sector.

[11] N. Pfund and B. Healey also attempt to evaluate the federal support for the timber and coal sectors, but they do not present any cohesive juxtaposition, unlike nuclear energy, petroleum and gas, biofuels and renewable energy sources (Pfund, Healey, 2011).

Chapter 3

Energy transformation of the coal paradigm: the World and the European Union

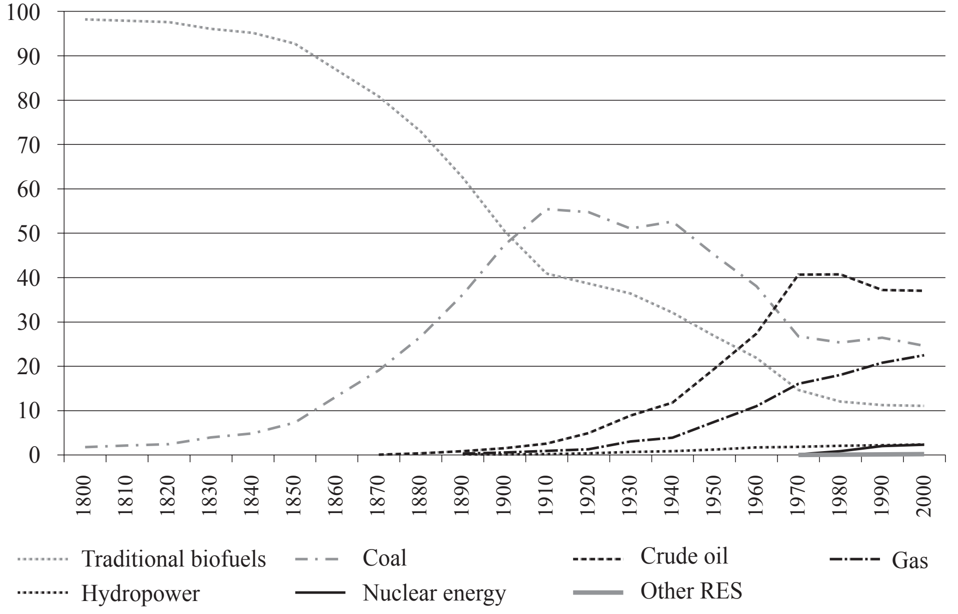
In performing a synthesis and analysis of the data with regard to the consumption of primary energy on the global scale over a longer period of time, it is to be noted that coal vied with traditional biofuels for the title of the main energy carrier. This does not mean that in individual regions or countries coal was no longer predominant, but from the perspective of two centuries and by adopting the proportions of the historical and traditional energy sources, the coal share will display a different distribution than the one we are accustomed to. For instance, in 1800, when coal had for a considerable period of time been a predominant energy source in England, the share of coal in the global structure of primary energy consumption can be estimated at only 1.75%, while the share of traditional biofuels – at 98.3% (Smil, 2017).[12] According to the analyses presented in the literature, the share of coal in the energy supply in England and Wales at the beginning of the 18th century amounted to almost 50% (Cf. Allen, 2009; Wrigley, 2010; Wrigley, 2013). Obviously, in the comparative analyses presented by individual researchers or institutions, one should draw attention to the kind of energy structure that is presented, and the kind of energy sources that have been included within it.

By holding onto the sources and data presented by V. Smil and some supplementary contemporary data presented by BP and IEA, it is to be noted that on a global scale a substitution of the coal technology was not as dynamic as it is presented in the case of the studies of the industrial revolution. But this observation concerns the inclusion in the energy consumption structure of traditional biofuels, which is what V. Smil did. According to these data, the coal share in the structure of primary energy consumption at the beginning of the 19th century is estimated at 1.75%, in the mid-19th century – at 7.3%, at the beginning of the 20th century – at

[12] The calculations are based on the data from BP, IEA and: Etemad, Luciani, 1991; Smil, 2017, pp. 239–243. The pre-1965 data used in calculation were drawn from the publication by V. Smil; they were also juxtaposed with the publication by B. Etemad and J. Luciani. The data concerned with the scope of traditional biofuel consumption are drawn from the publication by V. Smil. It is also worth focusing attention on various methods of collecting data, as a result of which research papers and data concerned with energy production and consumption may differ substantially. The research work by R.G. Newell and S. Iler, entitled *Global Energy Outlooks Comparison Methods* may serve as an example of a unifying analysis which shows differences in the estimates of primary energy consumption (Newell, Iler, 2017). The authors present differences in the methodology employed by such institutions as BP, EIA, ExxonMobil, IEA and OPEC.

47.3%, in the mid-20th century – at 45%, half a century later – at 24.5%. These data show that coal reached approximately a 50% share in the global structure of primary energy consumption at the beginning of the 20th century, still maintained its position in the mid-20th century, but at the beginning of the 21st century its share was more or less 25%. This results from the fact of the development of new trajectories of energy technologies and energy substitutions. V. Smil connects these transformations with new technologies, which he terms driving forces of globalization; he reckons among these diesel engines and gas turbines (Smil, 2010c). The presented data show that coal's dominance is to be observed during the second industrial revolution; it is also a driving force of the third industrial revolution, but the wide-ranging processes of economic transformations are possible owing to the new energy carriers and technologies (See Figure 6).

Figure 6. Global structure of primary energy consumption in the years 1800–2000 (in %)



* Percentage calculations on the basis of data from BP, IEA and Smil, 2017. Data since 1965, excluding traditional biofuels, come from BP and have been juxtaposed with IEA data.

* The term 'traditional biofuels' includes biomass, mainly as burnt wood and other burnt organic material.

* 'Other RES' does not include wind and solar energy, which are not depicted in the diagram.

Source: Own study.

As the significance of coal increases, the significance of traditional energy sources – that is, traditional biofuels – decreases. By the mid-19th century their share in the global structure of primary energy consumption was 92.7%, and half a century later the share of traditional biofuels amounted to 50.5%. However, it must be borne in mind that the global consumption of traditional biofuels amounted to more than 7222TWh in the mid-19th century, and at the beginning of the 19th century – to more than 6111TWh, while in the subsequent decades the consumption displayed an upward trend, but the rises were not to be as dynamic as the ones concerned with gas and oil in the period between 1960 and 2000.

By adopting two thresholds of substitution of energy technologies and carriers, that is a 25% and 50% share in the global structure of primary energy consumption, it is noteworthy that coal gained a 25% share as late as the 1880s, that is during the second industrial revolution, while the 50% share threshold was attained between the first and the second decade of the 20th century. However, if we do not include traditional biofuels in the structure of primary energy consumption, then coal was an absolutely dominant energy carrier in the global structure of primary energy consumption at the beginning of the 19th century and in the mid-19th century. By contrast, in the first decade of the 20th century, its share reached 95.6%; in the 1950s the share amounted only to 61.5%, but it was 16.5% higher than in the case when traditional biofuels are included in the energy structure.

The analysis of the change in the significance of coal was chiefly concerned with the percentage share in the global structure of consumption. According to the quantitative data, from the beginning of the 19th century till the beginning of the 21st century overall coal consumption was on the rise. At the beginning of the 19th century almost 5653TWh of energy was globally consumed; half a century later, the amount increased by almost 38%, one century later – the original value was doubled, one century and a half later – it was almost five times as much, two centuries later – the amount consumed was almost twenty times as much. And, accordingly, in the case of energy generated from coal, at the beginning of 1800 the amount consumed was more than 97TWh; half a century later – almost six times as much; one century later – almost sixty times as much, one century and a half later – almost one hundred and thirty times as much; two centuries later – two hundred eighty five times as much.

Leaving aside the unified analysis based on the data by V. Smil, BP and IEA, the above discussion can be compared with the data concerned with the total supply of energy, which is required to meet the needs in a given area (TPES). This indicator is used by IEA, and more or less it corresponds to the category of the gross national electricity consumption, which is employed in the Eurostat analyses. Because of the development of new energy technologies and processes of energy substitution since the 1950s, coal has been gradually losing its dominant position in the energy structure (TPES). In 2000 oil is the dominant carrier, and its share amounts to 37.1%, coal comes second (22.8%), then gas (20.5%), biofuels and waste (10.1%), nuclear energy (6.7%) (data from: *EU Energy in Figures Statistical Pocketbook 2017*, 2017; *EU Energy in Figures Statistical Pocketbook 2018*, 2018).[13] Despite the ongoing de-

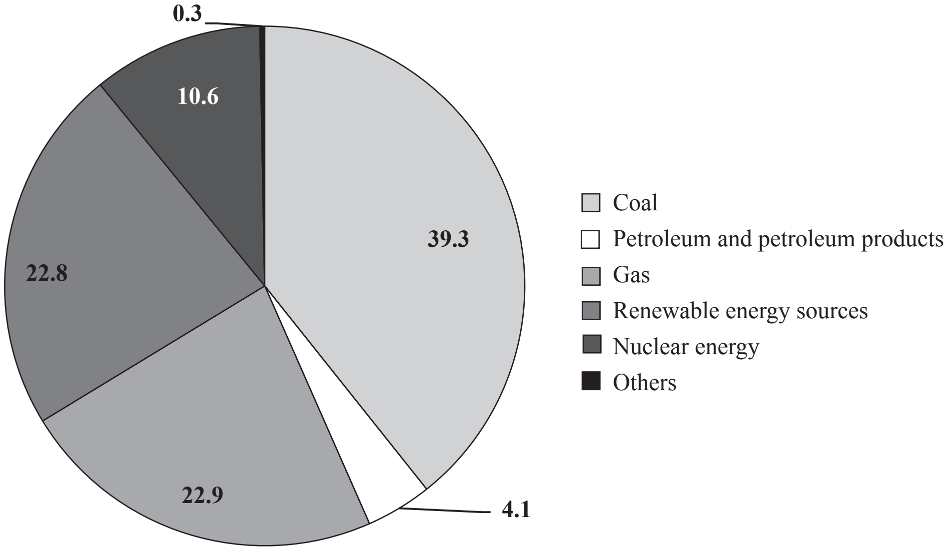
[13] Even though the European Commission refers to the IEA data concerned with primary energy supply in its report, there are slight differences in the presented data with regard to the production of primary energy in comparison with the IEA data.

bate about the energy transition concerned with the substitution of renewable energy technology and sources in the TPES structure, renewable energy sources do not hold a significant position. Even if we regard new kinds of biofuels and hydropower, the share of renewable energy sources is still less than 5%. Therefore, it is justifiable to conclude that in the global energy consumption, a total share of renewable energy sources in fact remains scant. Hence, the hydrocarbon paradigm appears to be the dominant one on account of the remarkable advantage of oil, coal and gas in the TPES structure. In 2015 the sequence of the main energy sources in the structure did not change – oil (32.3%), coal (27.8%), gas (21.4%), biofuels and waste (9.6%) and nuclear energy (4.9%). Still, it must be pointed out that in the period in question demand for energy increased. For instance, compared with 2000, in 2015 consumption of electricity produced from coal increased by more than 66%.

By contrast, the global structure of electricity production looks different; here, coal is still the dominant carrier. For instance, in 2000 6005TWh of electricity was produced from coal (solid fuels), which accounted almost for a 39% share in the then global structure of electricity production. In 2015 almost 59% more electricity was produced from coal in comparison with 2000, which translated into a 39.3% share in the global structure of electricity production. In the TPES structure oil is the dominant carrier, while the significance of oil in electricity production decreases – in 2015 oil accounted for more than a 4% share in electricity production. At the same time, it is worth pointing to the increase in the significance of renewable energy sources and gas, because they become a kind of substitute energy which enables a transition in the electric power industry both on the EU and global level (See Figure 7). Therefore, it can clearly be seen that despite the changes in the electric power industry, on a global scale coal still preserves its privileged position.

If we approach the sphere of the energy industry as a challenge, then the problem that remains is the one concerned with preparation of conditions in such a manner that it is possible to effectively deal with threats facing both the international community and individual countries. Undoubtedly, the challenges facing the international community include climate change and declining energy resources. Coal burning belongs to the group of more significant problems concerned with low-emission policy planning. In the first place, in order to make appropriate political and economic decisions, future trends in energy technologies should be identified; forecasts will serve this purpose. The main mechanisms in the sphere of the energy industry – excluding the influence of political and social entities – are the ones concerned with the market and innovation processes. The 21st century has brought an increase in competitiveness between economic entities which supply energy, but one should also bear in mind the increase in efficiency, which is related to the introduction of new technologies. But the transition speed is not certain, which comes to be reflected in various development scenarios presented by scientific, political and economic institutions. For instance, in 2018 BP drafted six scenarios which present potential paths of future consumption of primary energy, along with ascribed CO_2 emission scenarios.

Figure 7. Global electricity production by source in 2015 (%)

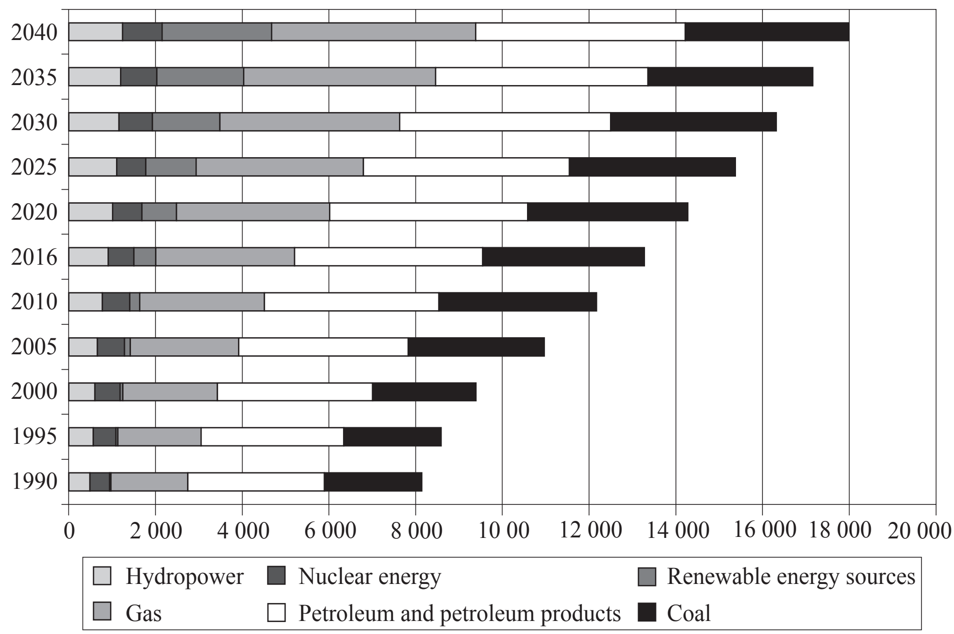


Source: Own study on the basis of IEA and Eurostat data.

Apart from the base scenario, an evolutionary transition scenario, BP presented: (1) a scenario excluding use of combustion engines, (2) a scenario of less gas switching, (3) a scenario of renewables push, (4) a scenario of faster transition, (5) a scenario of even faster transition (*BP Energy Outlook 2018*, 2018). Apparently, radical changes are only possible with strongly determined political, social and economic entities (Cf. Moallemi, Malekpour, 2018, pp. 205–216). Deepened processes of competition or innovation may be independent factors affecting economic entities. Given a lack of pronounced determination on the part of political entities, the scenario of evolutionary transition is more possible. However, it is noteworthy that determined implementation of the energy and transport policy brings significant results, pushes new trajectories of development in the sphere of energy technologies. Changes in the energy sector in Germany and Denmark, and changes in electromobility in Norway may serve here as examples (Cf. Holtsmark, 2012, pp. 4–11; Figenbaum, Kolbenstvedt, 2013; Holtsmark, Skonhoft, 2014, pp. 160–168; Slowik, Lutsey, 2016; Hampton, De La Cruz, Huenteler, 2017, pp. 1–17; *Denmark: energy and climate pioneer...,* 2018; Mey, Diesendorf, 2018, pp. 108–117). While considering the problem of choice of strategic energy trajectories, it is worth invoking a proposition by R.G. Lipsey, K.I. Carlaw and C.T. Bekar concerned with innovation, whereby non-adjustment to competitors in development of new technologies is an error costlier than inadequate pricing or inappropriate efficiency (Lipsey, Carlaw, Bekar, 2005, p. 86).

As regards the scenario of evolutionary transition, which comes second among the scenarios least conducive to the reduction of CO_2 emissions, the quantitative share of coal in the structure of primary energy consumption remains at a similar level compared with the 2016 level (See Figure 8). A similar situation is to be observed in the predictive analyses by the IEA, which in the reference scenario presupposes that while the percentage share of fossil resources will continue decreasing towards 2060, coal will still have a quantitatively considerable share in the global structure of primary energy demand. Thus, the IEA assumes that 2060 – compared with 2014 – will witness an absolute rise in fossil fuel consumption by around 27.7PWh (approx. 100EJ), that is by 22%, given the fact that the whole rise in demand for fossil fuels is supposed to concern petroleum and natural gas, while the consumption of coal is to remain steady (*Energy technology perspectives...*, 2017). By contrast, the BP scenario also presupposes an increase in CO_2 emissions by 10% by 2040, but the speed of emissions rise will not be as high and as big as in the period between 1990 and 2016. Yet, in this scenario renewable energy sources

Figure 8. Forecasts of global energy consumption in 2040 (evolutionary scenario) (Mtoe)



* Renewable energy sources comprise wind energy, as well as electricity produced from solar energy and other renewable sources. Other products, next to crude oil, include biofuels, and fuels obtained from gas and coal.

* BP chose the 2020s and onwards as the beginning of the scope of forecasting of the energy path dependence. The presented scenario is of a base character (evolutionary scenario) and includes baseline conditions familiar at the moment of forecasting.

Source: Own study on the basis of BP data.

are the sources of energy that rise the fastest. An increase in the significance of renewable energy sources is possible due to the rising competitiveness of wind and solar energy. These changes may contribute to the emergence of the most diversified energy structure in which each one of the fossil fuels and the total of non-fossil fuels would each have a ¼ share in the global structure of energy consumption. According to the scenario assumptions, the EU will be a leader of the low-emissions policy, as well as of energy efficiency to the point that it will be consuming more or less the same amount of energy as in 1975, despite its level of GDP being more than three times bigger (*BP Energy Outlook 2018*, 2018). Other parts of the world are expected to witness a rise in the significance of coal, especially the places where the speed of urbanization and industrialization processes is high or does not decrease; various scenarios for the development of India or other Asian countries may serve here as examples.

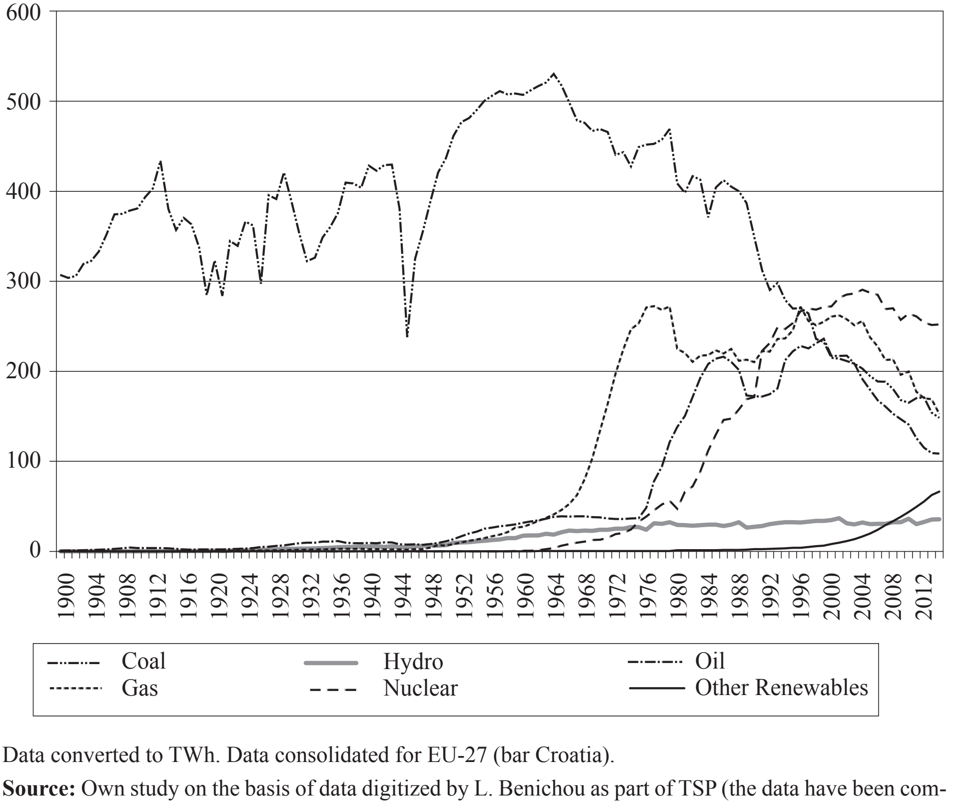
The BP analyses concerned with potential development paths of energy sectors should be supplemented with a presupposition of the possibility of more dynamic development of new coal technologies, e.g. CSS, which will constitute a factor affecting the sustained significance of coal in energy structures, if not at the global or regional levels, then at least at the level of individual countries. Much attention is due to the development potential of the CSS technology, which can be used in both the burning processes employed for capturing noxious emissions and the processes of the manufacturing of steel, hydrogen, artificial fertilizers, bioethanol, as well as the processes of coal gasification. Apparently, the greater the motivations of political, social and economic entities are, the greater the significance of CSS will be. According to the predictive analyses performed by the IEA, along with the increase in the climate-related ambitions, CSS will be characterized by greater interest on the part of political, social and economic entities, because it can lower the emissions related to industrial and energy-related processes (*Energy technology perspectives...*, 2017). It also appears that of great significance here will be political entities whose role will consist in supporting logistics and financial solutions. On the other hand, it must be borne in mind that the increasing environmental burden imposed on the industrial sector – given a lack of possibility of cost externalizing – will result in the sector itself introducing low-emissions solutions even more rapidly. For instance, in 2014 the industrial sector accounted for 38% of global energy consumption and 24% of CO_2 emissions. Thus, that is a great potential which can be used with a view to supporting technological development.

While considering the energy potential of the EU-27 countries,[14] the dependence of the EU member states on coal, but also the speed of energy transition, it is noteworthy that in a period of more than a century coal as the main carrier was dominant in the structure of primary energy production. The EU territory attained a relatively diversified energy structure, with a modest share of renewable energy

[14] The synthesis has been performed with regard to EU-27 (not EU-28) on account of a lack of available data that could be unified in such a long period presented in the analysis.

sources, only in the 1990s. For instance, in 1996 hard and lignite coal accounted for 25.2%, gas – 25.3%, nuclear energy – 24.9%, oil – 21.3%, and hydropower along with other renewable energy sources – almost 3.4%. I can also be noted that on account of intra-institutional dynamics of the EU and the individual member states (new trends in the international and internal policies, action by social entities, but also a new institutional framework of the EU itself), further EU energy processes and changes take place. By contrast, in 2014, despite the change in the overall attitude to nuclear energy, the biggest share in the structure of primary energy production was the one of nuclear energy – 33%. Then came gas – 20%, coal – 19.4%, oil – 14.2% and renewable energy sources – 13.4%. A change in the percentage share of the individual sources may not depict the import of the energy processes and changes of a quantitative character, and so in order to depict the trends in the energy structure transformation, it must be pointed out that over a period of almost two decades, production of primary energy from coal dropped by 45%, production of primary energy from oil dropped by 52.5%, while the nuclear energy drop was only 5.5% (See Figure 9).

Figure 9. Production of primary energy by source in the EU-27 in the years 1900–2014 (in TWh)



Data converted to TWh. Data consolidated for EU-27 (bar Croatia).

Source: Own study on the basis of data digitized by L. Benichou as part of TSP (the data have been compared to the BP, IEA and EIA data, as well as publication: Etemad, Luciani, 1991).

Since the 1960s the gas share in the structure of primary energy production in the EU gradually increased, and remarkably so in the 1970s; at the end of that decade the trend was reversed, with the upward trend returning in the first half of the 1990s. The period between 1996 and 2014 witnessed a downward trend in the gas share in the production of primary energy; in that period a drop in the production of primary energy from gas amounted to 44%. In a sense, oil replicated the upward trend followed by gas in the EU member states, but this time the trend took place in the 1970s, and not the 1960s, which was the case of gas. It might seem a little surprising, because the significant rise took place in the period of oil conflicts and the debates about threats to state security caused by disruptions to crude oil supply. However, it must be borne in mind that this period witnessed exploitation of new petroleum reserves not related to the Middle East, for instance in the North Sea.

By looking at the whole century, one can notice a long shift from a complete monopoly in the structure of the production of primary energy from coal to a highly diversified structure. To quote a term by G.C. Unruh, mentioned before, a techno-economic coal complex was dominant in this period; furthermore, in some member states it is still particularly significant and markedly limits the speed of energy transition. In 1900 the territory of the EU member states was totally associated with coal as the main carrier in the structure of primary energy production; back then, the share of this resource amounted to 99.7%, hard coal accounting for the majority. Oil was another carrier in the structure, but its share was only 0.25%. By contrast, in 2000 in the territory of the EU member states the structure of primary energy production was considerably diversified, but it must be borne in mind that in that period overall energy production increased – from 3077.7TWh to 10081.5TWh, that is almost thirty-threefold. Hence, that period witnessed a drop in the share of coal in primary energy production, but the comparison of the data from the beginning of the 20th century with the data from the end of the 20th century shows the drop to be of 30%. In 2000, the share of hard and lignite coal amounted to 21.3%, nuclear energy – 27%, gas – 25.8%, oil – 21.5%, water and other renewable sources – 4.3%. Similarly, coal's share in the structure of electricity production in the EU in 2000 was significant, that is 32%.[15] This means that coal also remained an essential carrier in the commercial energy industry, which can clearly be seen in some EU member states, for instance in Germany and Poland.

While considering the dominant energy structures in the EU territory, it remains debatable what should be regarded as the tipping point for the advantage gained by the coal technology. What degree of energy structure diversification would be viewed as sufficient to consider that the trajectories that might constitute important trajectories of energy technology development have significantly

[15] The percentage calculations have been made by the author on the basis of actual data digitalized by L. Benichou as part of TSP (the data have been juxtaposed with BP, IEA and EIA data as well as with the publication: Etemad, Luciani, 1991).

developed or that a substitution of energy carriers has taken place? Performing further analysis of the transformations in the structure of primary energy production, it is noteworthy that despite the economic dynamics in the 1950s, the energy structure did not change much. In 1955 coal was still the dominant energy source in the structure of primary energy production, and its share was 90.6%, while hard coal alone accounted for 74.5%. However, an increase in energy production generally results in the production of primary energy from coal rising by 63% compared with 1900. At the same time, oil's share in the energy structure is slight – 2.5%, gas – 2.7%, and hydropower together with other sources of energy – 2.2%.[16]

In the mid-1960s coal continued to maintain its position, but an increasing role was played by gas, oil and renewable energy sources, and the sector of civilian nuclear energy was also booming. In total, all the carriers which were not lignite or hard coal accounted for almost 18% in the structure of energy production. The demand for electricity kept rising, and so did production of primary energy. Lignite coal and hard coal together accounted for an 82% share in the structure of primary energy production, but hard coal alone accounted for only a 63.1% share.

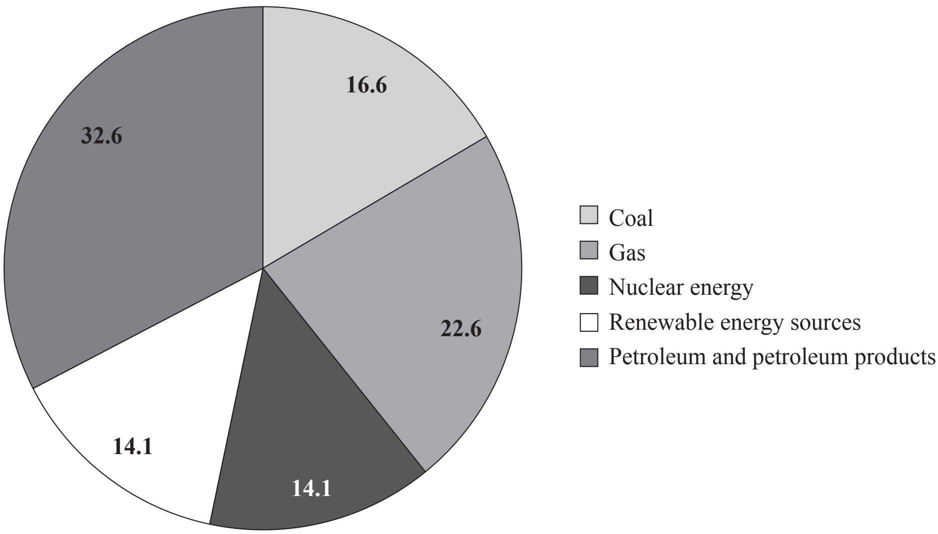
Compared with 1965, ten years later, the increase in the production of primary energy in the EU-27 amounted to almost 27%. Of ever greater significance was gas, the share of which in the production of primary energy increased fivefold in that period. Coal's percentage share in the production structure dropped down to 56.2%; the drop of the percentage share of hard coal alone was also significant, as it fell down to 39.6%. In the mid-1980s a rise in the production of primary energy in the EU-27, compared with 1965, amounted to 59%, while compared with 1975, the rise was of 25.4%. The second half of the 1980s saw a markedly declining significance of coal; in 1966 the production of primary energy from coal amounted to 5170.5TWh, in 1975 – 4491TWh, in 1985 – 4041.6TWh, in 1995 – as little as 2695.5TWh. Apart from gas, nuclear energy is also useful in the decarbonization of the production of primary energy in the EU-27; in 1975 the share of this type of energy in the structure of energy production was already 4.1%, in 1985 – 12.9%, in 1995 – 24.7%. Compared with 1975, in 1995 production of nuclear primary energy increased by a factor of 7.5.

Leaving aside the unified analysis based on the data from the EU-27 in the period between 1900–2000, one can compare the above discussion with the data concerned with the total primary energy supply (TPES) for the EU-28. In 2000 in the European Union, like in the case of the global energy structure, petroleum and petroleum products were the dominant sources of energy, petroleum's share accounting for 36.9%. The next positions were taken by gas – 23.4%, coal – 19%, nuclear energy – 14.5%, while renewable energy sources had a 6.2% share in the

[16] The percentage calculations have been made by the author on the basis of actual data digitalized by L. Benichou as part of TSP (the data have been juxtaposed with BP, IEA and EIA as well as the publication: Etemad, Luciani, 1991).

TPES in the EU-28.[17] Even though in 2015 the TPES structure did not display any change in the order of the first positions of energy sources, that is regarding oil, gas and coal, there was a visible rise in the share of renewable energy sources in the structure of energy supply up to 14.1%. Thus, the share of renewable energy sources drew level with nuclear energy, which too had more than a 14% share in the structure of energy supply. It can be concluded that given the drop of quantitative share of gas in the primary energy supply by around 10%, and of nuclear energy by 9.3%, it is renewable energy sources that take on significance in the decarbonization of the energy supply structure. Coal's share in the structure of energy supply for EU-28 amounted to 16.6%, which meant a drop, while in absolute terms coal's share fell by more than 18%, and yet coal remains the third biggest source of energy (See Figure 10).

Figure 10. Structure of total energy supply in EU-28 in 2015 (TPES)



The actual values have been converted to a percentage share. Neither the calculations nor the diagram includes electricity or heating flow. The category of renewable energy sources encompasses hydropower, geothermal energy, solar and wind power, as well as biofuels and waste.

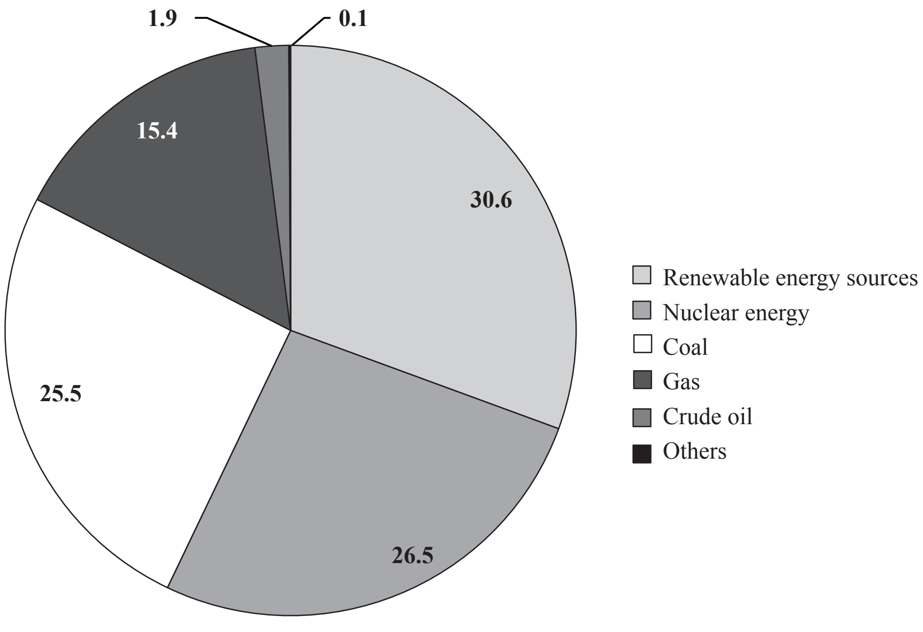
Source: Own study on the basis of IEA data.

It is worth comparing the TPES structure with the production of electricity in EU-28, as the juxtaposition of the two will show a pronounced difference. In 2015 the first position in the structure of electricity production was taken by renewable energy sources; then came nuclear energy, coal, gas and oil. Fifteen years earlier coal was the main carrier in the production of electricity, while renewable energy sources accounted for more than a 15% share, with hydropower

[17] The percentage calculations have been made by the author on the basis of IEA data. The data do not include electricity or heating flow within the TPES structure.

having a share of more than 83% in the electricity produced from renewable energy sources. As we compare the data with the ones from 2000, we can conclude that the electric power industry is undergoing a considerable transition, with its peculiar processes of decarbonization and a rise in energy efficiency (See Figure 11).

Figure 11. Structure of electricity production in EU-28 in 2015



The actual values have converted to a percentage share. The category of renewable energy sources encompasses biofuels, waste, hydropower, geothermal energy, PV, solar thermal power, wind power, marine power.
Source: Own study based on IEA data.

Over a period of fifteen years, in the structure of electricity production coal dropped from the first position to the third one; compared with 2000 in absolute terms, coal's share diminished by 14.6%, while compared with 1990 it fell by 21.3%. In comparing the energy structure in 2000 with the one in 2015, it must be pointed out that the share of oil and nuclear energy decreased too, while the share of gas increased to slightly over 3.5%. Apparently, for many of the EU-28 member states gas is going to constitute one of the mechanisms of substitute energy, which will combine cost-effectiveness with low emissions, which will however be connected with an increase in import dependency. It is worth drawing attention to the trends in the development of the sector of renewable energy sources. While earlier on most of the energy generated with the aid of renewable energy sources came from hydropower, in 2015 hydropower's share amounted to 37.5%, wind energy – 30.5%, biofuels – 15.9%, PV – 10.3%. There is no doubt that of great relevance for the decarbonization and development of renewable energy sources were the social and political entities in the EU which influenced one another. The institutional framework for these changes was established, inter alia, with the aid of energy packages as well as climate and energy packages.

Chapter 4

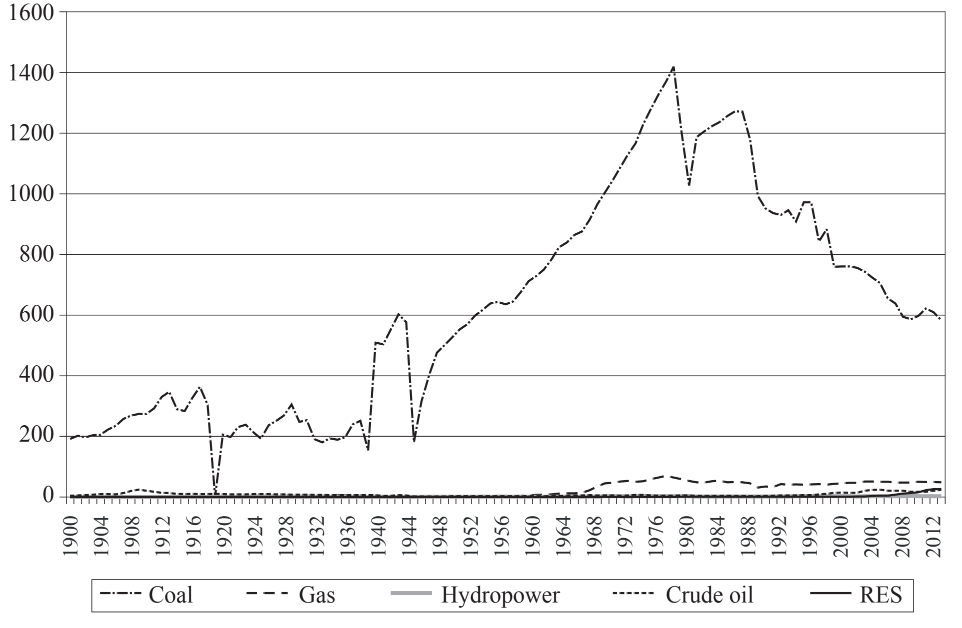
Energy transformation of the coal paradigm: Poland

By drawing on the data synthesized by L. Benichou as part of the TSP activity (while comparing them with the BP, EIA and IEA data, as well as the publication by B. Etemad, J. Luciani), it is possible to present changes in the production of primary energy in Poland in the years 1900–2014. Considering the differences that feature in the data concerned with energy production and consumption, e.g. the data used by Eurostat, for the sake of comparison use will also be made of the data made available by the IEA with regard to the TPES trends and electricity production. The aim of such an approach is to point to and describe general trends in the energy sector in Poland in the 20th century and at the beginning of the 21st century, as well as to supplement them with more detailed issues.

The analysis of the trends in the production of primary energy in the first two decades of the 20th century, and the two decades of the interwar period reflects basic propositions concerned with the economy in the Polish lands, which are presented in the studies of the Polish industry. The technological revolution which was still underway in the Polish lands towards the end of the 19th century resulted in increased industrial production and a rise in the production of primary energy. The data concerned with primary energy produced from coal show drops in or changing dynamics of the production in the periods of war and in both cases of state consolidation after the warfare was ended. By comparing the decades of the interwar period with the first two decades of the 20th century one can also see that the trend in the production of primary energy is parallel to the industrial production. Hence, all the problems concerned with both the internal and external economic slump, also with regard to political factors such as a tax war with Germany, come to be reflected in the production of primary energy (See Figure 12).

As of the second half of the 1940s we can observe considerable progress in the production of coal-based primary energy. For instance, the period between 1949 and 1979 witnessed a rise in the production of coal-based primary energy of almost 184%. The year 1980 brought the first considerable drop in the production of energy, which was related to internal political and economic factors, but also to a change in the overall economic situation on international markets. The drop in the production of coal-based primary energy in the period 1979–1985 amounted to almost –13%. Another visible drop which in fact triggered a general trend in the declining production of primary energy – despite occasional rises – took place in the second half of the 1980s. The trend continued into the 1990s and the two consecutive decades in the 21st century. For instance, the drop in the production of coal-based primary energy in the years 1988–1993 amounted to –26.8%, while the drop in the period of 1988–2014 amounted to more than 54% (See Figure 12). The analysis of the whole period of 1900–2014 reveals a total dominance of coal in the production of primary energy, which results mainly from Poland's resource potential; at the same time of note is a lack of resolute exploitation of the potential of renewable energy sources, especially at the end of the 20th century and the beginning of the 21st century.

Figure 12. Primary energy production in Poland in the years 1900–2014 (in TWh)

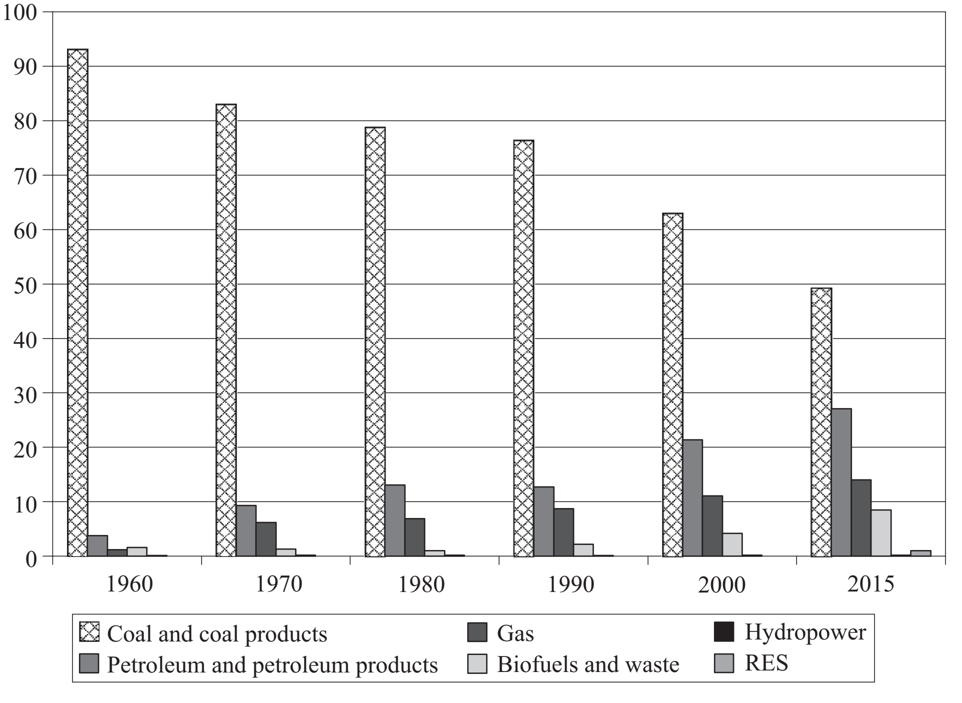


Source: Own study on the basis of data synthesized by L. Benichou as part of TSP (data compared with BP, IEA and EIA data as well as the publication by Etemad, Luciani, 1991).

To get a bigger picture of energy production in Poland it is also worth presenting an analysis of the total supply of primary energy, that is energy required to provide for Poland's internal consumption. The year 1960 was regarded as the starting point, which results from an instrumental move – availability of cohesive data – as well as a subject matter move – the persistent dynamics of energy production and consumption in Poland, and the continuous upward trend in the industrial production. The trends in the total supply of primary energy are identical with the overall trends in the production of primary energy in Poland. Compared with 1960, the year 1980 witnessed an increase in the total supply of primary energy, which amounted to almost 134%, while the drop in 2015 – compared with 1980

– amounted to 25%. The change in the economic structure, development of successive branches of economy, and transformations in the energy structure revealed the diminishing share of coal in the total supply of primary energy. At the same time petroleum and petroleum products, gas and biofuels were gaining more and more significance. In 2015 coal's share decreased and dropped below 50%, while – compared with the 1990s – the percentage share of oil and gas in the total supply of primary energy increased more than twofold. In 2015 renewable energy sources were only slightly significant, with their 1% share. An assessment of the transformation of the total energy consumption in Poland in 1960–2015 would show a gradual transformation of the coal-based economy towards new carriers such as oil and gas (See Figure 13).

Figure 13. Structure of total supply of primary energy in Poland in 1960–2015 (in %)



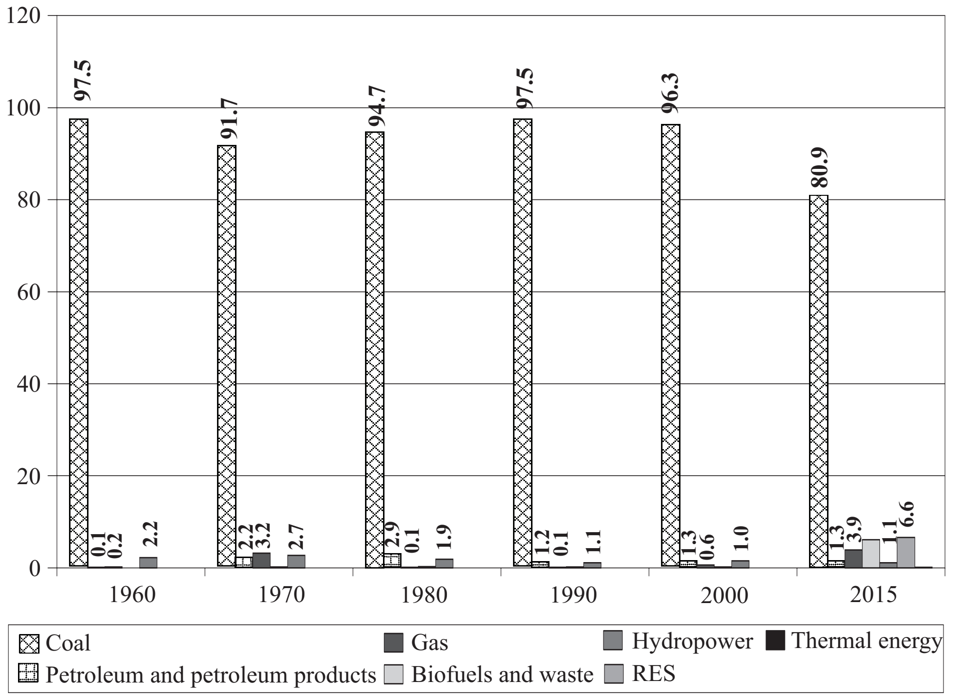
Percentage values have been rounded off, in individual years RES and electricity data have not been provided due to very small values.

Source: Own study on the basis of IEA data.

According to the presented periods in the analysis of the changes in the total supply of primary energy, an analysis of the structure of electricity production in Poland may be performed. By way of a tentative assumption, if hard and lignite coals are the dominant carriers in the production of electricity in Poland, then this will show in the analysis of the structures of energy production in the period of

1960–2015. Remarkable growth dynamics of energy production can be observed between 1960 and 1970, as well as between 1970 and 1980. Both in the first and second case the production increased twofold. A dominant role in this growth was played by hard coal, while a 3.6% drop in coal's share in the production of electricity can be observed in 2000–2015. Unlike the changes in the structure of the total supply of primary energy, changes in the structure of primary energy production do not display such visible carrier substitutions. This in turn proves that the transformation of the coal-based energy generation is the slowest here. For instance, in 2015 the subsequent positions in respect of significance were taken by such electricity production carriers as renewable energy sources (6.6%), biofuels (6.1%) and gas (3.9%). None of the carriers, or energy technologies reached 25%, to say nothing of a 50% share in the structure of electricity production. It can only be concluded that the enumerated carriers exceeded the 3% tipping point necessary for adaptation (See Figure 14).

Figure 14. Structure of electricity production in Poland in 1960–2015 (in %)



Percentage values have been rounded off, in individual years RES and thermal energy data have not been provided due to small values.

Source: Own study on the basis of IEA data.

Moving on to general issues concerned with various energy structures in Poland throughout the 20th century and at the beginning of the 21st century, it is worth shedding some light on selected particular problems. At the turn of the 19th and

20th century, in the Polish lands, the first public and commercial power plants were put into operation, e.g. in Szczecin (1889), Wrocław (1890), Bielsko-Biała (1893), Grudziądz (1894), Bydgoszcz (1896), Gniezno (1901), Poznań (1903), Warszawa (1904), Kraków (1905) (*Historia elektryki polskiej*, 1972, pp. 485–492). Municipal power plants generated electricity which was then converted into mechanical energy to drive machinery and vehicles. In those days the dominant type of current was direct current produced at factories to provide lighting. An increase in the demand for lighting in urbanized areas gave rise to the establishment of municipal power plants. According to J. Łukasiewicz, at the end of the 19th century, in the Polish lands occupied by Austria and Prussia, with the exception of Silesia, municipal power plants were the main suppliers of electricity. Until 1907 in the Kingdom of Poland there were only two municipal power plants in operation. By contrast, in the Kingdom of Poland 108 industrial power plants were commissioned in the years 1895–1905 (Łukasiewicz, 1974, pp. 29–44).

Electric motors became most widespread in the mining industry, especially in the lands of Upper Silesia. In mining, electric motors were often used as drive in drainage pumps and lifting machinery. New technologies in the processes of production of coal and other resources made Upper Silesia a significant consumer of electricity. Close to mines large power plants were constructed, while mines were no longer just an addition to the smelting industry. In 1912 the total capacity of mining power plants amounted to 98.4MW, while two years later – 149.5MW. Power plants were also opened in other mining and smelting regions, e.g. in 1911 in Dąbrowa Basin nine mining power plants were in operation, with the total capacity of 20.8MW. On account of the specificity of the industry it was more difficult to adapt electricity to smelting processes. J. Łukasiewicz writes that power plants began to be constructed next to smelting plants in the last decade of the 19th century, but in the rolling industry they became popular only in the second half of the first decade of the 20th century (Jaros, 1969, pp. 12–25; Łukasiewicz, 1974, pp. 29–44).

While analyzing the state of industrial power plants in the Kingdom of Poland in 1911, it is noteworthy that 165 power plants with a total installed capacity of 49.58MW were in operation, 42% of which accounted for the mining sector, 23% – textile industry, 8.8% – smelting industry, 8.7% – metallurgical industry. Therefore, according to the data presented by J. Łukasiewicz, the highest rate of electrification was to be found in the mining and textile industries, which also came to be reflected in the scale of the installed capacity of functional motors – the mining industry accounted for 38.5%, the textile industry – 22.5%. The author writes that in general there were around 200 power plants in operation in the Kingdom of Poland in 1913, while in the Polish lands there were around 400 power plants. It can clearly be seen that the energy infrastructure was unevenly distributed in the Polish lands. For instance, 60% of the installed capacity of the power plants accounted for Upper Silesia, while 20% accounted for the Kingdom of Poland. The majority of the infrastructure in that period generated direct current – out of the 200 power plants selling electricity, only 20% generated alternating current, but the capacity of their generators accounted for 75% of total capacity. The alternating current technology was dominant at power plants in Upper Silesia (85%) and the Kingdom of Poland (79%), while power plants generating direct current were dominant in the north-western part of the Polish lands. Similar proportions applied to industrial power plants in the individual parts of the Polish lands (Mejro, 1958, pp. 265–278; Łukasiewicz, 1974, pp. 29–44; Strzałka, Porada, 2016, pp. 31–39).

Electrification of cities is concerned with the use of electric drive in municipal transport. The first electric tram in the Polish lands came into operation in 1891 in Wrocław, and between the middle of the last decade of the 19th century and the beginning of the first decade of the 20th century trams were commissioned in fifteen towns in the Polish lands, mostly in the western lands. In that period, in the Kingdom of Poland, trams were put into operation only in Łódź, and in the lands annexed by Austria – in Cracow and Bielsko. In Upper Silesia, an electric network of narrow-gauge railway was developed; it connected the major places in the industrial center. Then, on a smaller scale an electric network of narrow-gauge railway was developed in Łódź, while in Warsaw such a network was commissioned in 1908 (*Historia elektryki polskiej*, 1971, pp. 33–157, 372; Łukasiewicz, 1974, pp. 29–44).

In the meantime, the production of electricity underwent various processes of innovation, e.g. the first decade of the 20th century witnessed considerable changes in the construction technology of power plants. Substitution of energy technologies concerned with piston engines took place at that time. This technology was replaced with steam turbines, and more efficient boilers were installed. The capacity of the electricity-carrying transmission lines developed during the interwar period was between 6 and 15kV, and at times as high as 30kV. However, the country was not covered by an even network of electrification; particular disproportions were to be observed in the countryside (*Elektryfikacja*, 2018). In the Polish lands it was the introduction of power engineering that gave rise to propagation of new kinds of motors and new sources of energy (Łukasiewicz, 1974, pp. 29–44).

The years 1918–1939 were a period of consolidation of the Polish state under new socio-political conditions. After the national independence had been regained, the three territories that had previously been partitioned off required unification. And so did several areas disparate in respect of the socio-economic structure; these included Silesia, the former Kingdom of Poland, Greater Poland, Pomerania, West Galicia and the so-called Eastern Borderlands (Landau, Tomaszewski, 1991, pp. 5–9). According to historians, in that period production was not restored to the level attained by the Polish lands in 1913. This proposition put forward by historians follows from a comparison of the total production indexes of 1913 and 1938, and respectively production indexes for selected industry branches (Kaliński, 2008, pp. 194–195). A comparative analysis of the state of production before and after the First World War was presented by Swedish economist I. Svennilson, who pointed out that Poland as the only one among major countries did not exceed the level of industrial production registered before 1914; what is more, *per capita* it was even lower by 5%. Poland had few industry branches, which due to a lack of financial and organizational possibilities could not develop on the periphery of the new state. The economic structure was of an agricultural and industrial character, and 60% of the population lived off agriculture. The internal market was not too extensive, and the demand for industrial goods was not as high as the one in other European countries (Jezierski, Zawadzki, 1966, pp. 254–255; Landau, Tomaszewski, 1991, pp. 71–79; Kaliński, 2008, pp. 194–195).

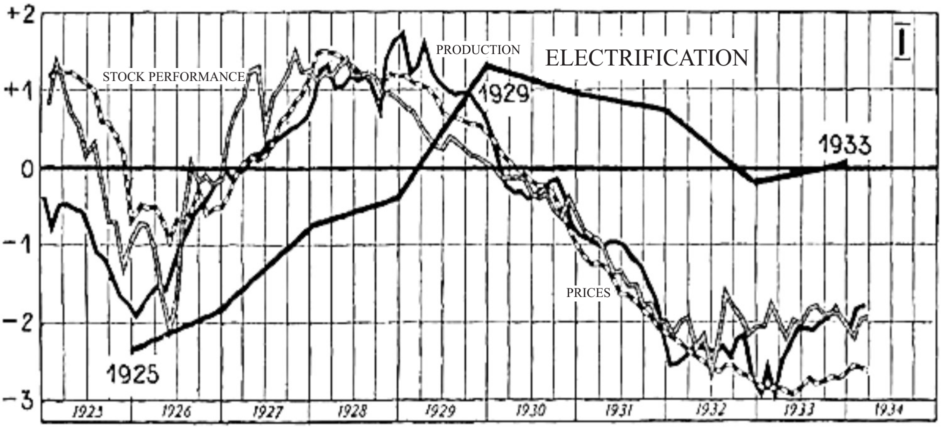
A. Jezierski points out that the main economic problems included disproportions of the development of the individual areas, disproportions of the development of the individual branches of industry, disproportions of the level of growth in the same industry branches, disproportions of the development of infrastructure (including the transport one), problems with the logistics of goods markets, problems with the logistics of raw materials (including fuels), problems with the disparities of institutional structures. It was difficult to stimulate the internal market if it was underdeveloped and to a large extent based on interchange of traditional goods, and consumers could not afford to buy the goods on offer. These factors made it difficult to introduce quick changes, and overcoming development limitations was not just about rebuilding of the country from the ravages of the war. A change to the export structure should be regarded as an external factor stymieing the country's development. For instance, the turnover of goods between the Kingdom of Poland and the Russian Empire amounted to $667M in 1910, while the turnover of goods between Poland and the USSR amounted to only $19M in 1930 (Jezierski, Zawadzki, 1966, pp. 251–254; Sutowski, 2015, pp. 176–186). Another factor limiting the development of the Polish industry was the necessity to compete with similar export products distributed in the markets by the USSR. Poland's biggest trade partners were Germany, the UK and the USA. Still, Poland's new territory and its resource potential made for great capacity for economic growth.

Because of the precarious border situation concerned with the territorial dispute in Silesia, Poland had no choice but to import large amounts of hard coal and coke until 1922. The situation changed when Poland acquired a considerable number of mines in Upper Silesia, thereby becoming a major exporter of this resource. Despite these changes, Poland imported small amounts of processed products such as coking coal and coke, which were to be used in the smelting industry. In the mid-1920s Germany attempted to destabilize the Polish economy by stopping the export of coal, which gave rise to the Polish-German tax war. In that period the German part of Silesia increased the hard coal output potential and developed lignite coal mining, which made for Germany's greater self-sufficiency (Jezierski, 1970, pp. 346–347). As a result of Germany stopping the import of coal from Poland, the production of this resource decreased in Poland. The considerable destabilization of the production of coal led to social problems, but also to an unfavorable economic position of the Polish coal companies. In the first half of the 1920s inflation targeting proved to be some support for the production of coal, as it enabled export of coal at competitive prices (Jezierski, Zawadzki, 1966, pp. 256–257).

J. Jaros presented the main problems concerned with the organization of this sector in the interwar period, which included a rather slow pace of technological advancement and of production efficiency. The progress only applied to selected areas of the processes of coal production. Efficiency was most often realized by stopping coal mining in low-yield deposits. According to J. Jaros a relatively better situation was to be observed in the German areas of Upper Silesia, where the production was maintained thanks to end users in eastern Germany. Comparing the results in 1913 and 1938, in these mines the output growth exceeded 136%. Considerable proceeds from the production of coal in the German part of Upper Silesia enabled further investments in the mining industry. However, it must be noted that the economic fluctuations in global markets affected the mining industry in both Poland and Germany (Jaros, 1973, pp. 18–20).

Poland was also faced with the problem of low dynamics of the investment in the electricity production sector and the whole electro-technological sector, which resulted from the insufficient economic growth, the unstable economic situation in the first half of the 1920s, and capital's interest in other sectors such as the timber and petroleum industry. A better economic situation was only to be observed in the second half of the 1920s, which witnessed an economic stabilization (Kühn, 1934, pp. 429–433). According to the data by the Institute for Market and Price Research, presented by K. Siwicki, until 1925 the electric power industry could not expect changes to electrification on economic and technical grounds. Apart from these factors listed by K. Siwicki, mention should be made of the disproportions in the use of coal in particular parts of Poland; these disproportions in themselves constituted an indicator of economic and technological growth, and at the same time – an assessment of the potential in the current and future energy use. In the years 1926–1929, the installed capacity of the commercial power plants increased by 86%, while their production by 118%; the number of towns which were electrified increased by 100%. In the period of an economic upturn, electrification is characterized by the same trend as industrial production, but comes with a lag of one year. Despite another economic crisis, electrification is more resistant than industrial production. For instance, the period 1928–1930 witnessed a rise in the value of sold electricity from PLN 146.6M to 177M, and the year 1932 saw a drop down to PLN 153.2M. According to K. Siwicki the data prove that in economic terms there was no crisis in the processes of electrification. What is more, the author points out that the processes of electrification in that period were hardly related to the operation of big industry (See Figure 15). Besides, the period of crisis shows an upward trend in the investment in electrification and telecommunication, and a drop in the investment in the network of rail and road transport (Siwicki, 1934, pp. 433–436). At the end of 1938 only 3% of all the villages were electrified (more than 1260 villages), while electrification of farmsteads reached 2% (*Elektryfikacja*, 2018).

Figure 15. Major indicators of the economic development and electrification index in Poland (1925–1933)



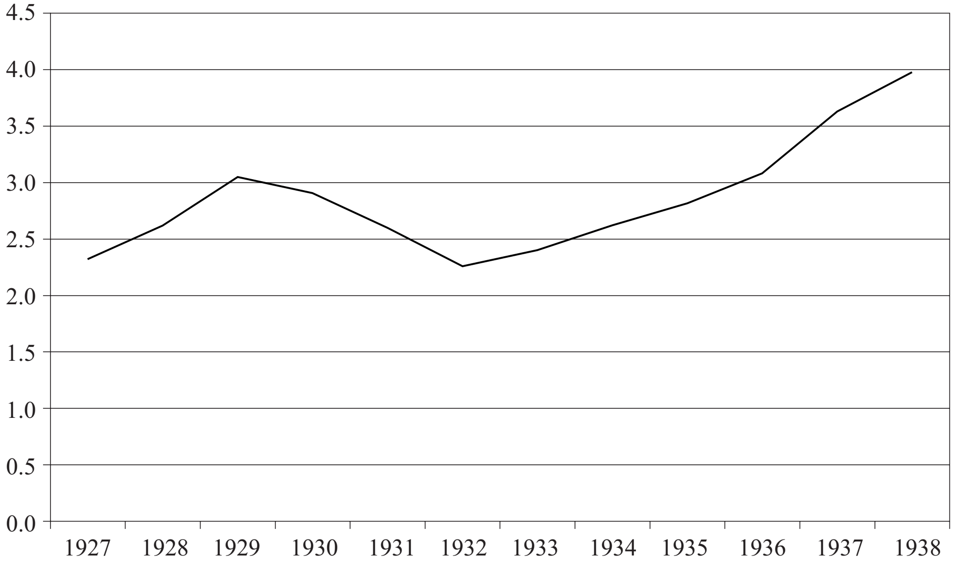
Source: Siwicki, 1934.

According to the Central Statistical Office data from 1939, prior to the 1928 global crisis there were 1645 electricity-producing companies with a total installed capacity of 1020MW, which yielded 2.618TWh of electricity. While comparing these data with the 1938 data it should be pointed out that the number of electricity-producing companies increased by 94%; the total installed capacity rose by 66%, and electricity production rose by 52%. With the Central Statistical Office data from 1927–1938 one can point to a visible drop in the production of electricity in the years 1931–1932, which was related to the overall economic situation (See Figure 16). In 1938 the structure of the installed capacity displayed dominance of the Silesian Province with its 34.4% share (a 41.8% share in the production of electricity), while the Kielce Province came second with its 16.6% share (a 15.2% share in the production of electricity).[18]

As regards the number of hard coal mining companies in 1928, it is noteworthy that it changed only slightly compared with 1913 – there were 90 mining companies in operation. However, the juxtaposition of 1928 and 1938 shows a drop of 30 companies. The number of employees in the sector also decreased from 128,100 to 80,700. The period between 1913 and 1926 shows a visible downward trend in coal extraction, the years 1928–1930 being marked by an upturn, and then a significant drop again. Another increase in extraction came in the second half of the 1930s (See Figure 17). Both in 1928 and 1938 dominant was the Silesian Basin, the production of which in 1913 accounted for 78.5%, in 1928 – 75.1%, while in 1938 – 75.6%. Throughout the interwar period Poland contributed 3% to the global coal production. Such a great output exceeded the state needs, and so in some periods

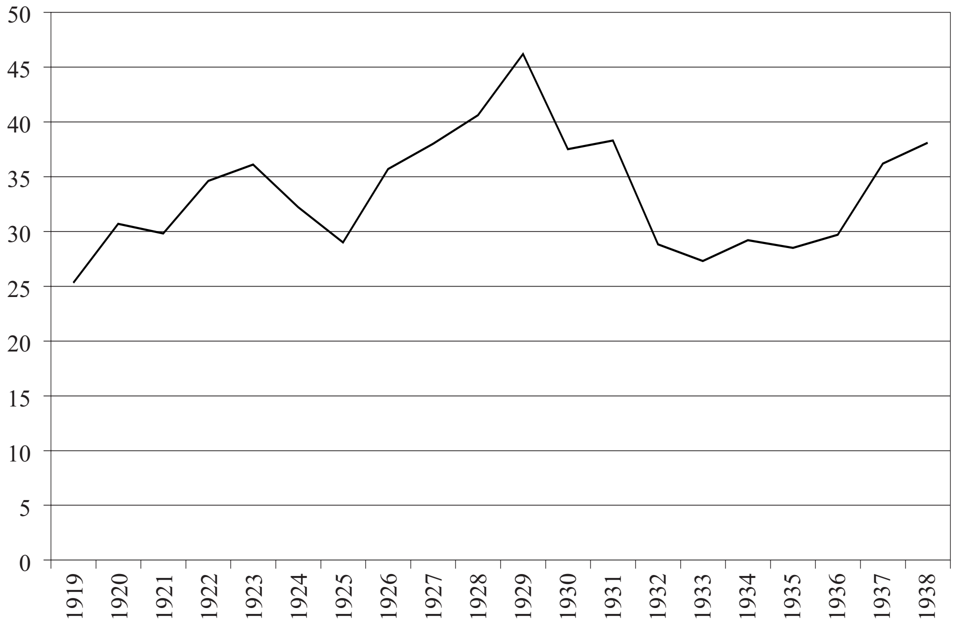
[18] Data on actual values obtained from the Central Statistical Office for 1939 (some of the data on actual values have been converted into other units). Percentage calculations have been made by the author – on the basis of 1939 data obtained from the Central Statistical Office.

Figure 16. Production of electricity in Poland 1927–1938 (in TWh)



Source: Own study on the basis of the Central Statistical Office data.

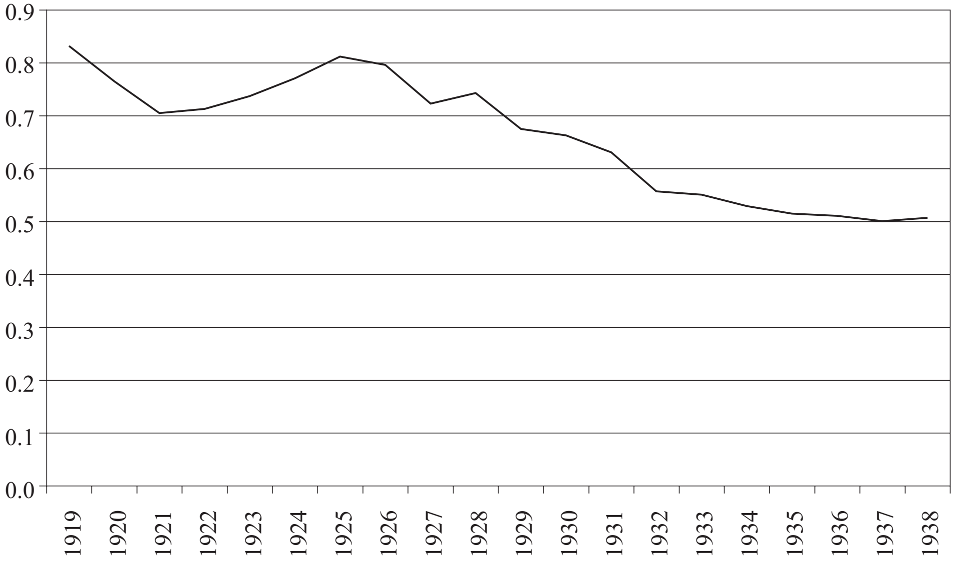
Figure 17. Production of hard coal in Poland 1919–1938 (in Mt)



Source: Own study on the basis of the Central Statistical Office data.

Poland exported as much as 40% of its coal. This led to a kind of dependence in trade exchange, which was stabilized by the exported coal. As regards mining, attention should also be focused on the production of oil, which decreased in significance in the years 1913–1938. Compared with 1913, in 1928 petroleum extraction decreased by more than 33%, while in 1938 – by almost 54.5%. This points to the diminishing significance of this mining sector, which was related to the depletion of the active deposits of crude oil (See Figure 18).[19]

Figure 18. Production of crude oil in Poland 1919–1938 (in Mt)



Source: Own study on the basis of the Central Statistical Office data.

It is worth pointing to the most energy-intensive and resource-intensive sectors of the economy in production processes. On the basis of the 1936 data by the Central Statistical Office, the sectors that in the production processes consumed the majority of hard and lignite coal included: metal industry (almost 30%), mineral industry (25.2%), textile industry (14.6%), food industry (almost 13%) and chemical industry (12.9%). Attention should be focused on the chemical industry; even though it is not ranked among the three industries consuming the majority of hard and lignite coal, this industry accounted for 86.2% of gas consumption and almost 86% of oil consumption in production processes. Besides, the chemical industry ranked first in respect of own electricity consumption (37.2%), and second in respect of purchased electricity consumption (28.1%). As regards purchased electricity consumption, the first position was taken by the metal industry (28.4%), which also came second in respect of own electricity consumption (25.6%).[20]

[19] Data on actual values provided by the Central Statistical Office for 1939. Percentage calculations by the author – on the basis of the Central Statistical Office data for 1939.

[20] Percentage calculations made by the author – on the basis of 1939 data obtained from the Central Statistical Office.

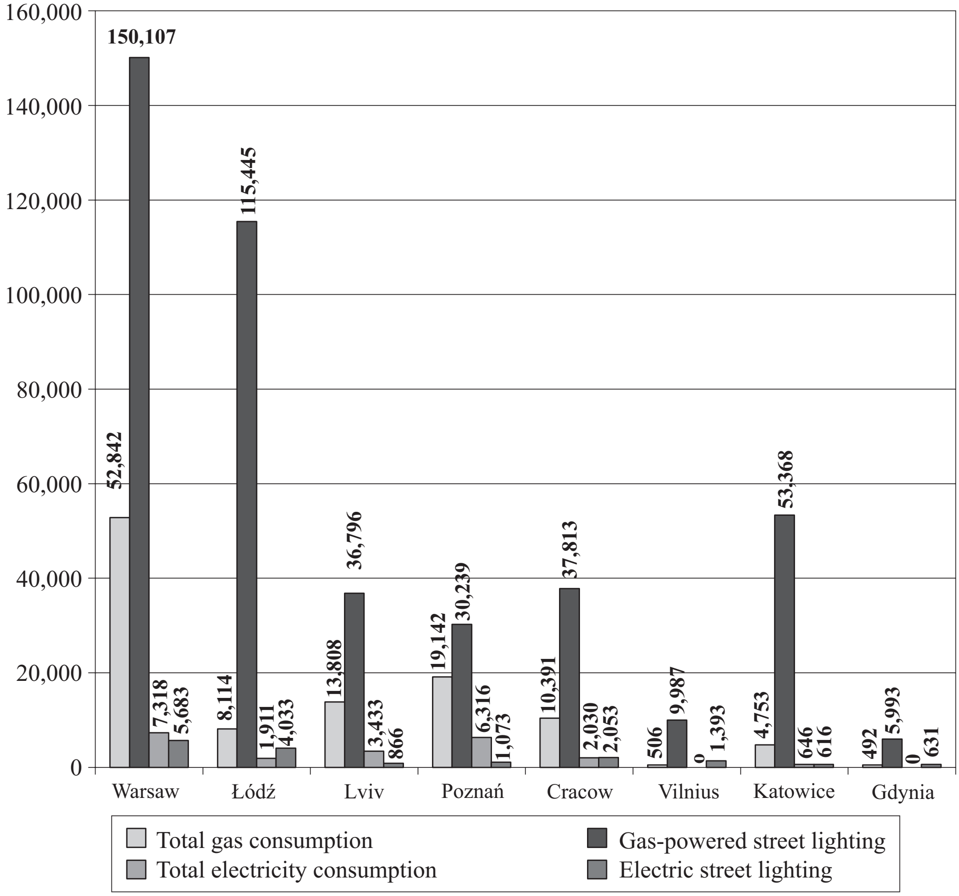
Also, it is worth analyzing non-industrial end users of electricity and selected resources. Poland's progressive urbanization and technological advancement make it necessary to track the overall structure of electricity and gas consumption in the major Polish cities. According to the 1937 data Warsaw was the city that consumed the most electricity (34.1%), then came Łódź (26.2%), Katowice (12.1%) and Cracow (8.6%). The city consuming the largest amount of electricity was also the one that consumed the most gas – Warsaw (48%), then Poznań (17.4%), Lviv (12.4%) and Łódź (7.3%). The analysis with regard to the overall consumption of electricity and gas singled out consumption for street lighting, which may serve as an indicator of life quality and degree of urbanization. With regard to the electrification of lighting, in the group of the singled-out cities first came Warsaw (34.7%), then Łódź (24.6%), Cracow (12.5%) and Vilnius (8.5%). A comparison of the electricity consumption for street lighting in 1913 with the 1937 consumption in Warsaw reveals an increase of 414%. The highest degree of gas lighting, measured by the amount of gas consumed for that purpose, was registered in Warsaw (33.8%); then came Poznań (29.1%), Lviv (15.8%) and Cracow (9.3%). A comparison of gas consumption for street lighting in 1913 with the consumption in 1937 in Warsaw reveals an increase of 158%. The consumption rate alone may not be enough to show a respective level of demand for electricity, and so it is worth considering *per capita* consumption. In 1937 the largest *per capita* amount of electricity was consumed in Katowice (99.7kWh), then came: Cracow (53.1kWh), Gdynia (51.1kWh) and Warsaw (46.6kWh). In the same period, the largest *per capita* amount of gas was consumed in Poznań (44.2m^3), then in: Warsaw (36.3m^3), Cracow (34.2m^3) and Lviv (32.7m^3) (See Figure 19).[21]

The development of industrial regions in Poland was particularly relevant for the generation of demand for electricity and resources. The crisis, inefficiently dispersed economic projects as well as limited access to capital were the factors that gave rise to the decision to develop an industrial center in south-central Poland. The years 1936–1939 witnessed the implementation of the project of the Central Industrial Region. The main projected investments included: construction of dams and hydroelectric power plants, glassworks, as well as factories of tire rubber, cellulose, engines, airframes and weaponry (Landau, Tomaszewski, 1991, pp. 53–70). The year 1937 saw the launch of the investments including such projects as a heat and power plant in Stalowa Wola, a hydroelectric power plant on the Dunajec river, electricity transmission lines and gas pipelines, as well as plants of strategic significance for the country's defenses (Kaliński, 2008, pp. 186–189). M. Sutowski writes that extensive plans for industrialization, which at the end of the 1930s included even the fifteen-year plans for Poland's economic development, consoli-

[21] Percentage calculations made by the author – on the basis of 1939 data obtained from the Central Statistical Office. Percentage calculations of the shares of individual cities in the consumption of electricity and gas have only been made as part of the total consumption for the group of eight cities, that is Warsaw, Łódź, Lviv, Poznań, Cracow, Vilnius, Katowice and Gdynia.

dated the coal sector as the strategic one, and laid the foundations for a strong "coal lobby" (Sutowski, 2015, pp. 176–177).

Figure 19. Consumption of gas and electricity in selected Polish cities in 1937



Consumption of gas in thousands of m^3, consumption of electricity in thousands of kWh. Overall consumption is broken down into gas and electricity consumption for street lighting.

Source: Own study on the basis of the Central Statistical Office data.

After the Second World War Poland was faced with more challenges – the significance of war damage and consolidation of the state under new territorial and socio-political conditions. Following the war, the new state encompassed 67% of the territory which had earlier belonged to Poland. This means that the effort to consolidate the social, political and economic aspects of the state was to be made once again. The 1950s saw an expansion of water and road transport; in those times shipyards in Gdańsk and Szczecin were opened, automobile and tractor factories were constructed. As for heavy industry, the steelworks in Częstochowa and Skawina were extended; a new steelworks in Nowa Huta was built. In 1950 an Act on “universal electrification of villages and housing estates” was passed. In the 1960s open-pit lignite mines were built in Turoszów and Konin, which strengthened the hard coal mining industry. Also, in that period the Rybnik Coal Area was extended, sulphur mining began in the environs of Tarnobrzeg, and copper mining in the environs of Legnica. The extension of the energy-intensive metallurgical industry was continued – in 1968 construction of the Głogów Copperworks began. The 1970s saw the beginning of the construction of a coal mine in the Lublin Basin, a lignite mine in Bełchatów, Katowice Steelworks, Głogów Copperworks II and a refinery in Gdańsk (Kaliński, Landau, 2003, pp. 266–268, 284–286, 304–309, 346–448; *100 lat Polski w liczbach*, 2018, p. 71). Investments and development in the Polish People’s Republic were subject to the cycles of the centrally planned economy, e.g. the 1st three-year plan (1947–1949), the six-year plan (1950–1955), the 1st five-year plan (1956–1960), the 2nd five-year plan (1961–1965), the 3rd five-year plan (1966–1970), the 4th five-year plan (1971–1975), the 5th five-year plan (1976–1980), the 2nd three-year plan (1983–1985) and the 6th five-year plan (1986–1990).

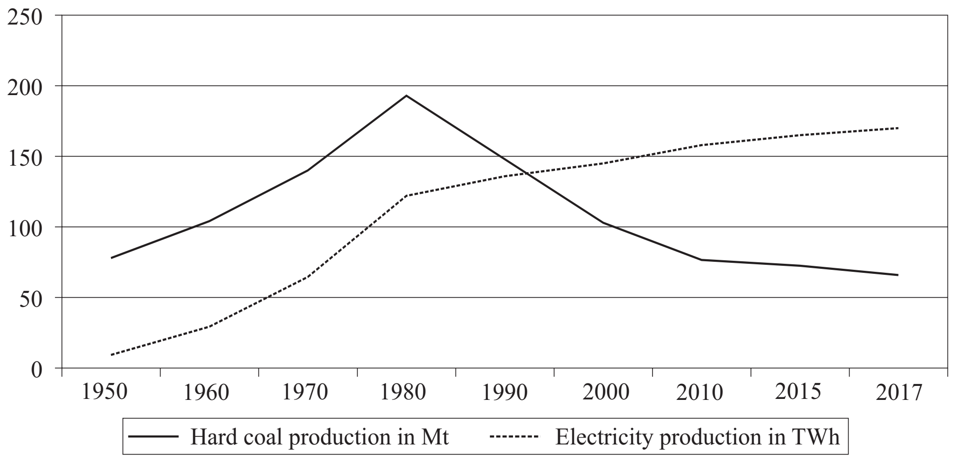
Along with the development of the energy-intensive industry in Poland came gradual electrification of villages and towns. Both before and after the war, visible were the disproportions of the electrification of villages and towns. In 1947 the first investment plan concerned with the electrification of the countryside was developed. For instance, in the second half of the 1940s more than 3500 villages were electrified, which accounted for just under 10% of the total number of villages (Bożentowicz, 2012, pp. 17–28). As early as the end of the 1940s the level of electrification reached 27%; the number of electrified villages increased by a factor of almost three and a half. Obviously, such a pace of electrification may be related to a problem concerned with an assessment of the quality of connections to the grid and electrical connectors in households. Quite a significant role was played by the significance of the individual agricultural regions with regard to their level of agricultural production. If we measure the level of electrification by the ratio of the length of the line to one household, it can be pointed out that in 1956 the length of the LV line was on average 61.4 meters, while ten years later – 106 meters. With the Act of 1950 as the element supportive of the six-year economic plan, electrification of individual areas continued. In the first place, electrification covered densely developed areas, and then scarcely developed ones. In 1950 the level of electrification of private farms in Poland was inadequate, as it only amounted to 20.9%; in the mid-1950s this level reached 36.9%, in the early 1960s – 58.3%, and in the mid-1960s – 79.2%. However, it must be borne in mind that as late as 1967 around 740,000 farmsteads – mainly in central and south-eastern provinces – were not electrified. There were still disproportions of the electrification levels, because at the beginning of the 1960s in western Poland more than 90% of farmsteads were connected to the grid; this rate did not apply to central and eastern Poland. At the end of the 1960s electrification reached 97%, which gave rise to the conclusion that the main goals of electrification had been achieved. As the electrification of villages progressed, public utility facilities such as schools, economic institutions, and even churches were connected to the grid. The electrification did not cover farmsteads in the dispersed mode of settlement, located far from major centers. At the beginning of the 1970s, on account of an increase in demand for electricity (e.g. in agricultural production) and an insufficient transmission infrastructure, modernization of rural power grids was begun (Bożentowicz, 2012, pp. 17–28; Tomczykiewicz, 2014, pp. 1–6; Komorowski, 2018, pp. 85–89).

Poland's economy and energy industry has been for the most part based on hard coal (and to a lesser degree on lignite coal). Mines became a social and economic problem the moment the political and economic transformation began at the beginning of the 1990s. Based on traditional energy carriers, the out-dated energy industry became a problem in the situation where requirements concerned with the natural environment protection were tightened, and energy markets were liberalized. The main factors impeding changes to the energy industry and the coal sector were of a social and political character. In the first stage of economic transformations in the 1990s, the coal sector served as a stabilizer of the free-market economy, with all its negative consequences for the economic condition of coal companies. However, it must be borne in mind that the main factors hindering the reforms included social and political factors, as well as the factor concerned with interest groups operating at the interface of the Polish coal complex and power engineering complex. Hardly effective restructuring programs, considerable financial costs incurred by mismanaged mines, substantial costs concerned with subsidizing the coal sector, a lack of radical changes in the conventional power engineering sector were the effect of all the enumerated factors.

It is worth focusing attention on the main trends in coal mining and electricity production in Poland in the period of 1950–2017. By that time, that is in the second half of the 1940s, like in the interwar period, coal became a stabilizer of trade exchange, and in this case a major source of foreign currencies. The obtained currencies were used to purchase both low- and high-processed goods abroad. Undoubtedly, the operation of the Polish economy and energy sector was still based on hard and lignite coal, which was to be clearly seen in the electricity production sector. While in the previous decades coal was the motor for the economy, now the hardly efficient mining sector became a problem for the possible scenarios of energy substitution.

In comparing the data on hard coal production in the period 1950–1980, one can point to the sustained upward trend in production. As early as the 1940s coal became a strategic resource, without which it was impossible to rebuild the country – its production between the end of the war and 1950 increased by 65.9%. In the second half of the 1950s the authority's attitude to the labor force in the mining sector changed; wishing to achieve higher productivity, the authority provided more financial support for miners. Edward Gierek was the driving force behind the directions of change with regard to raising the status of mining, though on a local level back then (Sutowski, 2015, pp. 186–198). In the period of 1950–1980 the percentage increase with regard to the presented data looked for every decade as follows: 33.3% in 1960, 34.6% in 1970, 37.8% in 1980. The percentage increase measured with the aid of the ratio of hard coal production in 1980 to the initial value of production in 1950 was 147.4%. On account of the effect of external factors such as the Council for Mutual Economic Assistance, as well as internal ones, such as institutionalized pressure groups in coal basins, and especially the Silesian Basin, the coal sector tremendously impacted the consolidation of the coal paradigm in Poland. This position was also maintained by the coal sector during the transformation of the Polish economy at the beginning of the 1990s. A comparison of the data on hard coal production in the period 1990–2010 reveals a downward trend. A percentage decrease in the coal production in 1990 amounted to –23.3%, in 2000 – –30.4%, in 2010 – –25.5%. The percentage decrease measured with the aid of the ratio of hard coal production in 2010 to the initial value of production in 1990 amounted to –48.1%. Also, the years 2015 and 2017 saw some drops (See Figure 20).[22]

Figure 20. Production of hard coal and electricity in Poland in 1950–2017



Source: Own study on the basis of the Central Statistical Office data.

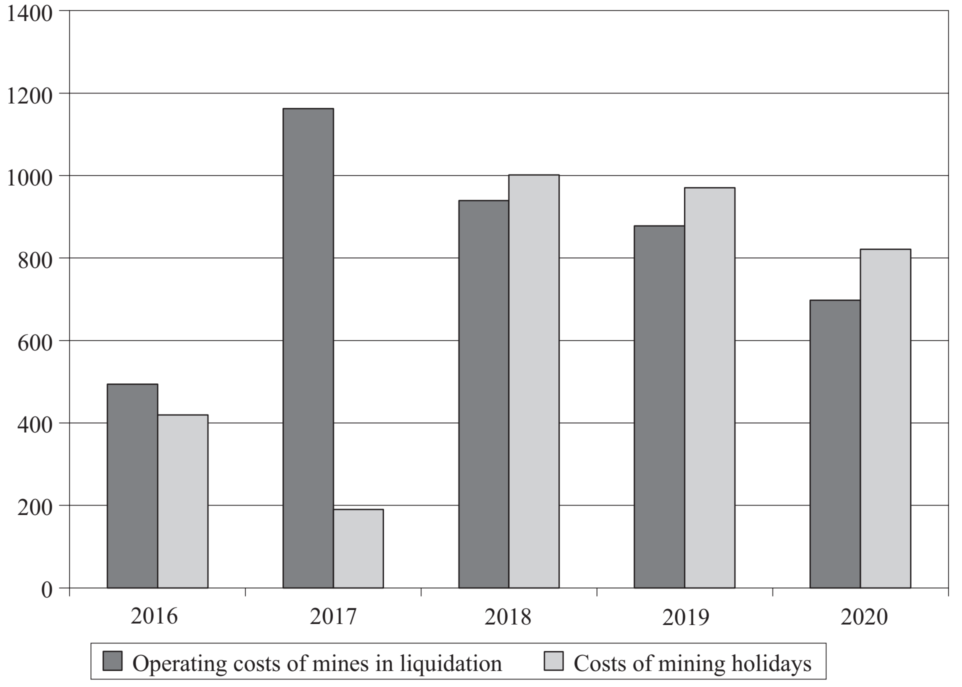
The main two factors concerned with the bad condition of the coal sector are mismanagement and frequent treatment of the sector as a *spoils system*, as well as low profitability of the mining industry, which is quite natural under the European conditions. Another problem facing the central government is the depletion of the deposits referred to as economic ones, which results in the necessity to prepare to tap new deposits. Exploitation of new deposits leads to increasing prices of coal and a drop in its mining. On the other hand, coal dependence is so high that in spite of the political rhetoric engaged in by some parties, the import of coal from Russia

[22] Percentage calculations made by the author – on the basis of the Central Statistical Office data for 2018.

keeps rising. For instance, in the first half of 2018, under the rule of the government coalition most skeptical of Russia, 7.5M tons of hard coal were imported, 68% of which came from Russia. The profitability of the coal output in Poland can also be depicted with the import of coal from the USA; in the period in question, it amounted to almost 10% of the whole import of coal into Poland (Bereźnicki, 2018; *Odpowiedź nr 23867*, 2018).

At this point it is worth drawing attention to the fact of great financial and organizational expenditure which was involved in the transformation of this sector. The first transformation of the coal sector took place in the years 1989–1992. In that period attempts were made to get rid of the central management of the sector, so that companies would become independent, and the opposition on the part of mining trade unions and mining companies themselves was eliminated. The second transformation of the coal sector took place in the years 1993–1995. The first stage involved restructuring of the sector by cutting the losses incurred by mining companies and increasing their profitability. In the next stage benefits related to mining employees' job security were prolonged, long-term contracts with consumers were introduced and the export was stabilized. A bad policy on stimulating internal competition in the coal sector led to the sector's increasing debt – indirectly by irrational increase in production and directly by unfavorable loans. At the end of 1994 the coal industry debt was estimated at PLN 6.7bn, while at the end of 1995 – 8.3bn. For the years 1996–2000 a special government program for the hard coal mining sector was developed, and for the years 1998–2002 a reform program was devised; it led to the closure of 23 mines and introduction of more benefits packages for mine employees. Another program to serve the hard coal mining sector was prepared for the years 2007–2015 (Karbownik, Bijańska, 2000; Czerwińska, 2002, pp. 1–8; Marek, 2006, pp. 269–283; Tkocz, 2006, pp. 28–38; Paszcza, 2010, pp. 63–81; Przybyłka, 2013, pp. 102–112; *Funkcjonowanie górnictwa węgla...*, 2017). Of particular note is the 2016–2020 program, which provided for subsidizing the hard coal sector with PLN 10.42bn, to which the European Commission granted its consent. According to the provisions almost PLN 5.5bn of that sum constitute costs of reducing the production capacity, while around PLN 3.5bn constitute social benefits. Of particular note is the structure of support for individual years in the period 2016–2020, because in 2016 26% of the subsidy was allotted to the operating costs of the mines in liquidation, and 22% to the costs of mining holidays, and respectively for the following years: for 2017 – 58% and 9.5%, for 2018 – 36% and 42.2%, for 2019 – 36.6% and 40.4%, and for 2020 – 33.6% and 39.6% (See Figure 21) (*Program dla sektora górnictwa*, 2017). It can clearly be seen that the considerable restructuring costs in this sector are made up of costs concerned with social benefits. In addition, the costs of coal production amount to 40–50% of wage costs, depending on the period. It must also be borne in mind that every year the mining sector pays into the national budget considerable sums, which in the period 2007–2017 amounted to between PLN 5.4bn and 8.9bn; annually, all public law liabilities made up between 0.77% and 1.48% of the national budget (*Program dla* *sektora górnictwa,* 2018). These data point to a financial symbiotic mechanism which in a special way constitutes an interdependence between the coal regime and the state structures.

Figure 21. Level of budget subsidies for the hard coal sector in the years 2016–2020 in millions of PLN, according to the draft of financial support program



Source: Own study on the basis of the Ministry of Energy data from 2017.

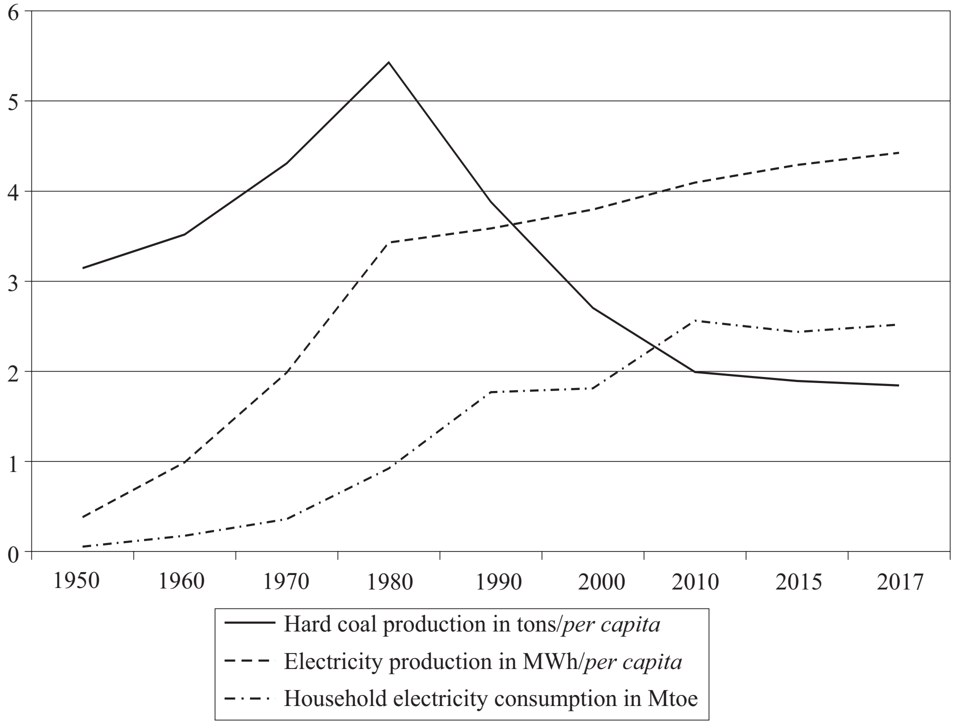
Whereas the analysis of the data on hard coal production in the period of 1990–2010 reveals a downward trend, the electricity production data show an upward trend not only in this time-frame, but throughout the whole of the said period. In 1949 electricity production amounted to only 8TWh, in 1950 – 9.4TWh, and in 1960 – 29.3TWh. In the years 1950–2010 the percentage increase with regard to the presented data was in every decade as follows: 211.7% in 1960, 120.1% in 1970, 89.1% in 1980, 11.4% in 1990, 6.6% in 2000, and 8.9% in 2010. The percentage increase measured with the aid of the ratio of electricity production in 1980 and 2010 to the initial value of production in 1950 amounted to 1198% and 1580% respectively. Rises were to observed in 2015 and 2017 as well (See Figure 20).[23]

In line with the drop in the overall hard coal production in the period of 1990–2010 was the decreasing index of *per capita* coal production. The percentage de-

[23] Percentage calculations have been made by the author – on the basis of the Central Statistical Office for 2018.

crease measured with the aid of the ratio of hard coal production (*per capita*) in 2010 to the initial value of production (*per capita*) in 1990 amounted to –48.6%. Further drops in *per capita* coal production took place in 2015 and 2017 as well. In line with the increase in electricity production was the increase in *per capita* electricity production. In the years 1950–2010 the percentage increase with regard to the presented data in every decade looked as follows: 159.7% in 1960, 101% in 1970, 72.6% in 1980, 4.6% in 1990, 5.8% in 2000 and 7.8% in 2010. The percentage increase measured with the aid of the ratio of electricity production (*per capita*) in 2010 to the initial value of production in 1950 amounted to 997.1%. *Per capita* increases in electricity production took place in 2015 and 2017 as well (See Figure 22).[24]

Figure 22. *Per capita* production of hard coal and electricity consumption at households in Poland in 1950–2017



Source: Own study on the basis of the Central Statistical Office data (the values have been converted to other units).

In order to supplement the analysis of the trends in coal and electricity production, changes in electricity consumption per household can be invoked. Changes in electricity consumption per household together with electricity production

[24] Percentage calculations have been made by the author – on the basis of the Central Statistical Office data for 2018.

(*per capita*) may constitute a broader perspective elucidating the meaning of the changes in electricity use in Poland; all the more so because in 2015 households accounted for more than 30% of end use of electricity in Poland. The analysis of the trend in consumption is all the more justified, because over several decades the demographic structure of the society was transformed, and qualitative changes took place in households. The period of 1950–2010 witnessed an upward trend in electricity consumption per household. A juxtaposition of the volume of consumption in 2015 with the volume of consumption in 2010 shows a slight drop. With the exception of 2012, the drop is to be observed in the period of 2011–2015. In the years 1950–2010 the percentage increase with regard to the presented data looked in every decade as follows: 236.2% in 1960, 107.8% in 1970, 156.9% in 1980, 92.1% in 1990, 2.32% in 2000, and 41.5% in 2010. The percentage increase as measured with the aid of the ratio of electricity production per household in 2010 to the initial value of consumption in 1950 amounts to 4895.6%. The data show that despite various demographic trends and the emergence of new energy carriers, one can observe a continued growth of household electricity consumption. For instance, a rise in the consumption of gas obtained from the network in 2010 compared with the initial value in 1950 amounted to 312.6%, while in farmsteads alone the rise amounted to 1408.6% (See Figure 22).[25] Attention should also be focused on the structure of per capita electricity consumption in households by particular energy carriers. In 2015 hard coal was still dominant in the structure of electricity use in households, with a 32% share. Then comes heating supplied over networks (20.6%), gas (16.8%), solid biomass (13.4%), electricity (12.9%), LPG (2.7%), light fuel oil (0.4%) and other energy carriers (1.2%) (*Energia 2017*, 2017). Particular energy carriers will have different shares depending on the purpose for which households will use them.

While analyzing the trends in the change in the energy structures in Poland, with the support of theoretical knowledge afforded by the studies of energy transformation, it is to be assumed that given a normal dynamic of change, substitution of coal as an energy carrier is possible within no less than 50 years. Any other scenarios will require more resolute action that would enable more extensive adaptation of current or new energy technologies. Any other path of development, whether based on renewable energy sources, or nuclear energy, without so much as institutional support is not possible to be realized at a fast pace. A serious problem concerned with making changes is the operation in Poland of a special kind of coal technology regime which manifests itself in the dominance of coal technology and infrastructure or technologies oriented thereto; it also manifests itself by the working of a specific organization which through operation by the agency of its own culture does not allow a dynamic development of other technological paths. The organization system should also include an institutional closure at the government administration level; through its format of operation alone and the goals it sets for

[25] Percentage calculations have been made by the author – on the basis of the Central Statistical Office data for 2018.

itself, this closure constitutes a mechanism blocking competitive solutions in the development of paths of energy technologies. This results from the fact of employing short-sighted political rationality in election cycles, which is concerned with minimization of the costs of political decisions, but also with the impact of economic entities as interest groups. The impact can even be seen with regard to the definition of strategic goals of Poland's energy policy, because an analysis of the composition of the bodies participating in the drafting of energy policy documents, or of the composition of the bodies providing analytical services used in the work on these documents is at least bound to get one thinking.

Conclusion

The neo-Schumpeterian trend developed studies of techno-economic regimes which in their logic of operation correspond to scientific paradigms. The issues concerned with the dominant technological regimes have been related to innovation systems that concern both technological and organizational aspects. According to Ch. Freeman and C. Perez, the main features of the new, emerging techno-economic paradigms – which would ensure greater efficiency in contrast to the old ones – should be relatively low and decreasing costs of solutions and technologies, unlimited access to them, their potential usability, potential adaptability in other sectors, potential for reducing the costs of capital, labor, products, etc.

The concept of techno-economic regimes has been used for analysis of energy regimes and transitions, which can be exemplified by the multi-level perspective presented by F.W. Geels. Along with the development of research into the relations between technology and society, the studies of techno-economic regimes in the energy sector began to widely draw on such trends as science, technology and society studies (STS), social construction of technology (SCOT), actor-network theory (ANT), technology assessment and its various specializations (TA) and constructivist technology assessment (CTA). At the same time findings of other research were used, e.g. studies of industrial economics, general purpose technology (GPT), a trend in research into techno-economic complexes (TIC) and many others.

The general assumptions of the dynamic of changes with regard to innovation in techno-economic regimes were borrowed from evolutionary economics. Hence, considerable emphasis was laid on the conditions for the emergence of technological innovations and their adaptation in regimes. The main research categories that characterize changes or the impossibility of their occurrence should include *path dependence* and *lock-in*. By way of illustration, in the sphere of the energy industry path dependence is related to the dominance of the coal sector in specific countries and specific periods, which made it impossible to develop competitive trajectories of energy technologies. These issues are depicted by three case studies presenting the working of coal paradigms (the world – the European Union, the United Kingdom and Poland). The analysis of the development of the individual energy trajectories as the object of research is particularly developed in the studies of energy transition.

Following B.K. Sovacool, one might conclude that it is difficult to present one satisfactory definition of the term of energy transition. Still, the characteristic trait of the studies of energy transition is about exploring the issues concerned with the substitution of major energy carriers (e.g. traditional biomass, coal, crude oil, gas) or energy technologies (e.g. coal, oil, gas, nuclear or solar ones). Over time, the studies of transition began to include an increasing number of factors affecting the pace of energy processes and changes. Also, energy technologies which are not dominant technologies in whole energy systems began to be considered.

The disputable issues concerned with the studies of energy transition should include an assessment of the speed and intensity of processes and changes. For instance, in tracking the pace of the growth of significance of coal between the first industrial revolution and the first half of the 20th century, one might draw conclusions different to the ones drawn if in the same period we took into consideration the significance of traditional biomass. While summarizing all the main issues concerned with the theoretical aspects of the studies of energy transition, attention should be paid to the following issues:

(1) an assessment of the factors affecting energy transition (e.g. social, technological and institutional factors);
(2) an assessment of the interdependence of the development of various trajectories of energy technologies (e.g. rail transport, road transport and resource transport);
(3) a threshold of adaptation of new energy carriers or technologies (e.g. 25% or 50% of the carrier share in the structure of demand for energy – V. Smil, A. Grübler);
(4) the tipping point in adaptation of various energy carriers and technologies (2–3% share in the market – C. Marchetti and N. Nakićenović);
(5) the initial threshold for assessment of the duration of adaptation (e.g. as regards crude oil, the first oil well operated by E.L. Drake in Pennsylvania in 1859);
(6) duration of transition (e.g. 5–10 decades or a transition from a 1% to 50% share in the market, with the time constant of 100 years – C. Marchetti and N. Nakićenović; time constants of 70 years for substitution of all carriers – A. Grübler and N. Nakićenović; time constants of market saturation of 50 years – A. Grübler and N. Nakićenović; between 80 and 130 years in the structures of primary energy – A. Grübler);
(7) a possibility of occurrence of fast energy transitions (e.g. Denmark with regard to combined heat and power; the Netherlands with regard to natural gas – B.K. Sovacool);
(8) disproportions of the duration of transition because of spatial diffusions of substitution of energy carriers and technologies (e.g. a transition from pre-industrial carriers to coal in individual European countries lasted between 46 and 160 years – A. Grübler);
(9) forms and patterns of transition: unilinear processes, multilinear processes, non-linear processes, untargeted processes, cyclical processes;
(10) an assessment of the significance of the demand factor;
(11) an assessment of the supply factor.

Following A. Cherp, V. Vinichenko, J. Jewell, E. Brutschin and B.K. Sovacool in the analysis of energy transition, at least three mutually interacting systems need to be taken into consideration. The first one is the techno-economic system, which comprises resources, demand and infrastructure. The second one is a socio-technical system, made up of innovation systems, technology diffusions, regimes and niches; while the third one is a political system, composed of state interests, political interests and institutions. All of the three systems and their component elements may be used in analysis of energy cultures of individual countries.

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