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Energy Transformation: Challenges and Opportunities — The Polish Case

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Abstract
The article, meant as the first in a series, tries to answer some questions around the future desired shape of the new Polish electro-energy mix in relation to the one described in the national energy policy document PEP 2040 (Energy Policy of Poland till 2040) and as compared with the targets set up in the newest UE legislative package, 'Fit-for-55'. In this article, I first present the rich overview of literature as well as economic theory behind the analysis of the energy transformation and energy-mix decarbonisation, in order to show how the energy mix should evolve in a way that will guarantee the biggest net gain to the society. Second, some comparable cost calculations on selected electro-energy sources, both LCOE (levelized cost of energy) and external costs are presented; these are modifications of my previous work as a co-author. Finally, the comparison of the 2040 electro-energy mix, as designed in the official governmental programme PEP 2040, with the two alternative scenarios, both of which exclude coal, and one also neglects the possibilities for nuclear energy to be included in the mix are presented. The alternative scenarios built into the paper are based on European Union (EU) plans to decarbonise Europe quickly. Recent geopolitical considerations related to the war in Ukraine, however, make it necessary to consider energy security as an important part of the plan. That would mean that nuclear energy would be a necessary component of the future mix in Poland. Security considerations are left to be analysed in the coming months, after a series of articles on lessons learnt by other developed countries in the process of making their energy-mix transformations and will complete the final recommendations for the future of the Polish energy mix.

1. INTRODUCTION AND LITERATURE REVIEW

The subject of an energy-mix transformation is well described in the literature. The most important initial hypothesis is that climate change is forcing the world to pursue decarbonisation in energy use. We can find evidence for this effort starting with the United Nations General Assembly level [UNGA Paris Agreement 2015; Fisher 2007; Fisher 2013] and on down to regional [Wewerinke-Singh 2021; Söderholm et al. 2011; Jacobs 2012; Luderer et al. 2012; Hansen et al. 2013; Fisher 2013; Capellán et al. 2016; Popkiewicz et al. 2019; Popkiewicz 2022] and national analysis [U.S. EPA 2019; Ha, Byrne 2019; Guo et al. 2020; Banks 2022]. The following references illustrate the vast number of energy-mix scenarios that underline the need to decarbonise the energy system [Das et al. 2007; ECF 2010; Williams et al. 2012; IRENA 2016; Fofrich et al. 2020; Wimbadi et al. 2020; Darby, Gerretsen 2020]. Again, the literature approach towards climate change and the need to decarbonise can also be found in the documents of the United Nations [IPCC 2018; UNFCCC 2020; UNFCCC 2021] and in the European Union policies of the European Green Deal [EU 2019; EU 2022a; EU 2022b] and other clear signals that the area should be regulated on the European level [ECF 2010; EC 2014; Minas 2020; Kulovesi, Oberthür, 2019]. The International Energy Agency recommendations can be found in the World Energy Outlook report [IEA 2020]. Quite a number of publications put the emphasis on human rights as well as the social dimensions of the energy-mix transformation, leading to conclusions that constitute a base for the just transition declarations of COP24 in Katowice and COP26 in Glasgow [Watkiss, Downing 2008; Center for Global Development 2016; Olsson et al. 2020; Wewerinke-Singh 2021]. The very basic problem of making the energy mix and the various dilemmas that accompany the process are also covered [Nakata 2004; Sovacool 2016; Laugs, Moll 2017]. The pivotal role of electro-energy in the energy-mix transformation is covered as well [Williams et al. 2012; EIA 2021a]. That is why I decided to concentrate this series of articles on the specific subject of electro-energy.

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There is a lot of research going on the need to constrain production of energy from fossil fuels and the direction in which the energy mix could change to accelerate the deployment of low-carbon energy technologies, including renewable energy sources (RES) [Cochran et al. 2014; IBS 2018; Valentine et al. 2019; Lederer et al. 2019; PIE 2019; Deloitte 2020; Keles, Yilmaz 2020; Blondeel et al. 2021; MacKinsey & Company 2021; Jonek-Kowalska 2022; Torres, Petrakopoulou 2022; Chorowski 2022]. Some will concentrate on single RE sources, like solar [Creutzig et al. 2017; Lazard 2020], bioenergy [Reid et al. 2019; Mandley et al. 2021; Ambaye et al. 2021] others point to the fact that the efficiency of RES (renewable energy sources) grows over the time and the prices of KWh generated drop, sometimes dramatically [Ringkjøb et al. 2018; Lazard 2020; Infield, Freris 2020; Christophers 2022; Banks 2022].

Individual focus is given to specific solutions that can be effective in decarbonisation of the energy mix, like the simultaneous use of natural gas and RES within a well-balanced energy mix, with strong potential to be used mainly in the United States and China [Pless et al. 2016; Xu et al. 2017; EIA 2021b; EIA 2021c] as well as the distributed or decentralised energy-production models, which could be used everywhere [Lund et al. 2019; Burger et al. 2019a; Burger et al. 2019b; Nyangon, Byrne 2022; Banks 2022; Strezoski 2022]. My alternative scenarios both follow similar models. Furthermore, a very important discussion, not only to my research, but also to the future of the planet, is the one on internalising negative externalities of fossil fuels that is covered by the vast literature. We can see that many economists, mostly environmental economists, had been active for decades now in promoting environmental Pigouvian taxes as a means to do the job. They are regarded as the key environmental policy instrument to force energy companies to make the proper choices, by internalising high social costs for using fossil fuels [Baumol, Oates 1971; Pearce 1991; Goulder 1995; Koeppl et al. 1996; Speck 2006; Anderson 2019]. It is important to note, that according to many researchers even if we are uncertain about the total social cost of using fossil fuels, a Pigou tax that is based on the best available estimates would be enough to signal to the energy companies that the social costs of the climate change have to be internalised. That is happening in the expenses that companies must pay as well as taxes levied on them to raise the private costs to a level of social cost that is higher than the private one. The pricing of the negative externalities of fossil fuels had been one of the most important pillars of modern environmental economics [Preiss et al. 2008; Pindyck 2013; Pindyck 2019; Andersson 2019]. Although it is beyond the scope of this article, it is worth noting that the literature proves that such taxes have no detrimental influence on employment or GDP growth [Metcalf, Stock 2020a; Metcalf, Stock 2020b].

Last, but not least of importance for my current article is the issue of the high cost of transformation of the energy-mix from fossil fuels to 'green' energy. Again, that is analysed from the perspective of the globe or of a region [Tol 2000; Baker 2021; Knuth 2021], separate states [Tanaka et al. 2017; Williams et al. 2021] as well as locally [Kennedy, Stock 2021]. Another important area of analysis for my deliberations here is the network cost of RES, which is represented in a large number of publications [Mai et al. 2012; Mai et al. 2013; D'haeseleer 2013; Fraunhofer 2015; ARE 2016; Al Matin et al. 2019; Burger et al. 2019b; Karkour et al. 2020; Pillai et al. 2021; Falvo et al. 2021; Veronese et al. 2021; Yang et al. 2022].

This literature review will be continued in the series of next articles that I plan, first by adding country-specific debates in articles covering transformation experiences of selected developed countries and by the Polish literature on the various possible scenarios for the future of the Polish energy mix, that I plan in the last article of the series.

2. LCOE AND THE ENERGY-MIX TRANSFORMATION THEORY

To structure the analysis, we can take as an example the view presented in *Environmental Economics and Natural Resource Management* [Anderson 2019] to follow the simple economic rationale explanation of a shift away from coal towards renewable energy sources, like, for example, solar panels (PV, photovoltaic). Let us start the analysis by equilibrium analysed in two axis diagrams, with the vertical axis showing the price of energy and the horizontal axis showing the quantity of energy supplied by the given source. Equilibrium occurs when marginal cost (MC private) equals the market price that represents marginal revenue (MR). If we create the diagrams to show green energy (like solar) versus fossil fuel-derived energy (like coal), the difference between private and social marginal cost shows all the externalities society faces when choosing a desired energy-mix. The energy transition from fossil fuels to RES presented will bring about benefits for both the environment and society. The improvements are the result of better air-quality as well as environmental quality and the potential creation of many new businesses in the energy and industry sectors including the creation of millions of new jobs [Europe 2017]. We can observe that green energy from RES is good for the planet, because it does not involve greenhouse gas (GHG) emissions and we now have scientifically supported, knowledge spill-over effects of those sources [Joskow 2020; Nyangon, Byrne 2021], whereas coal is not socially desired as an energy source because it causes GHG emissions harmful for the environment and air pollution that leads to many lethal diseases that put a burden on the society as a whole. Those in turn cause many causalities among ecosystems and humans – which burry a cost for the society – the social costs. Thus, the social marginal cost of using solar energy is lower than the private cost, and the social marginal cost of using coal is higher than the private cost. We have the capacity for a net gain in the transformation.

In Figure 1, we can see that the shift – a transformation process – that is producing less energy from coal, as

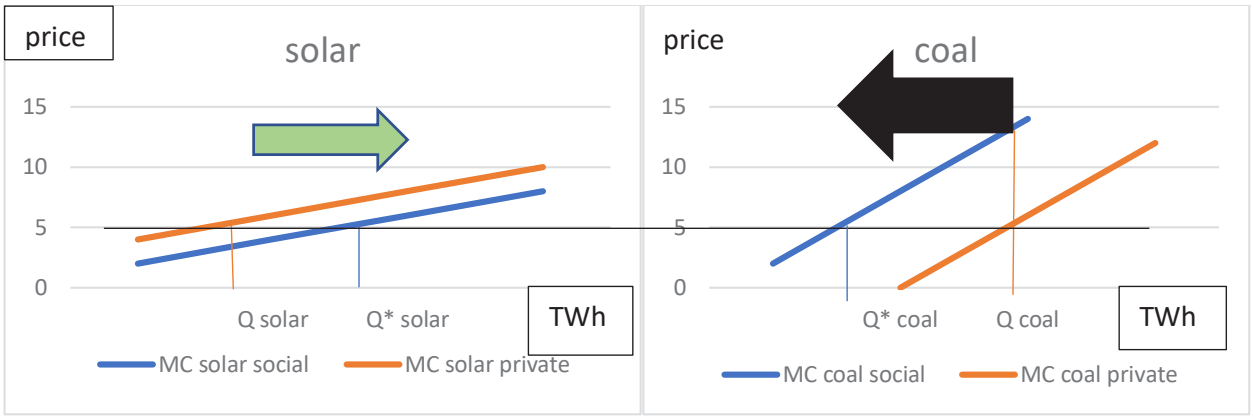


Figure 1. The transformation process – away from coal towards renewables.
Source: The author's adaptation on the basis of Anderson, 2019, chapter 7.

represented by the black arrow (the total cost saved by the reduction in energy production from coal is an area below MC_{coal} social cost curve between Q and Q*) as compared with the growth of the cost resulting from increased production of energy from solar sources, represented by the green arrow (the total cost increase is the area below MC_{solar} social cost curve between Q and Q*). We assume that the same volume of TWh (terawatt hours) of energy are being produced, within a different energy-mix as the result of the transformation. The net gain results from the fact that the social marginal cost of producing energy from coal is higher than the social marginal cost of producing energy from renewable sources. The larger the difference in social MC between solar and coal, the larger the net gain from the transformation. The proportions can be changed by subsidies and taxes, but that is beyond the scope of this article.

In concluding this section, we can say that the economics theory provides an answer to the direction in transformation of the energy mix that is desired by society. That transformation should move away from expensive (in social terms) sources of energy and into the most effective and inexpensive (again, in the sense of social cast) renewable sources. The evolution of energy prices from various sources as measured during the last decade can be taken from Lazard's Levelized Cost of Energy Analysis (LCOE). The technology-economics evaluation of energy plants is usually based on the LCOE analysis. The LCOE is an equivalent to the cost of producing a kilowatt hour (KWh) using a given source of energy. In general, LCOE is being calculated as the summation of the total costs incurred by the company divided by the total energy produced during the lifetime of its operations. The costs include: (1) the initial investment, (2) operation and maintenance (O&M) costs,) the fuel as well as consumable costs. The total MWh (megawatt hours) of energy produced in that plant can be adjusted by taking into account a proper degradation rate of the power plant [Papapetrou 2022]. Using that calculus, solar energy produced in the United States is now at less than 15 percent of its prices a decade ago [Lazard 2020].

Taking the lately fashionable orbital view, we can assess the transformation consequences for the globe. Let us consider the results of the comprehensive renewables-oriented energy transformation, on a basis of recent report on the economic benefits generated by the use of renewable energy. The study shows that the benefits of doubling the share of renewable energy in the global energy mix by the year 2030 would increase global GDP by 0.6 and 1.1 percent or, in monetary terms, $US 0.7–1.3 trillion. Also, this doubling of the renewables' share in global energy mix would increase employment by 24.4 million in that sector, also by the year 2030 [IRENA 2016].

3. PURPOSE AND METHODS

This article is meant to be an initial analysis of the various possible options for the future electro-energy mix of Poland, through the decade of 2040–2050. Governmental documents like PEP 2040 [Monitor Polski 2020] and the direction for possible amendments to it published last year [KPRM 2022] have already been made public. The scenario presented is far from reaching goals set in the FF55 package of the European Commission. It seems that the necessary changes will have to follow, as the emissions reduction is only a means to achieve climate neutrality, as described in the Paris Agreement, 'so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century' [UN 2015]. This paper is meant to give some advice about the process, by analysing three points in a series of articles. The first – by enlarging the discussion on the costs of various energy sources to encompass not only LCOE, but also social costs – that is the purpose of this first article in the series. The new abbreviation used in this paper is LCOE+, to reflect that distinction between private and social costs. The second, by drawing lessons that we can learn from other developed countries on the basis of their

transformation processes – already completed or in the process of implementation – will be presented in the next articles in the series, following various countries' strategies and developments in energy-mix form. The third part and the final article of the series, will sum up recommendations gained from both parts in in the series, on the possible composition of the Polish energy-mix for 2040–2050, which could be based on RES with only the necessary base of fossil fuels and nuclear energy. At that stage, it would be also advisable to check the attractiveness to the Polish case of distributed power system solutions as well as the energy efficiency question.

In this article, the simple model of calculating the LCOE+ of selected energy sources in the Polish electro-energy-mix is calculated with the cost relations based on PEP 2040, with some analysis of externalities. Negative externalities of fossil fuels (coal and gas) will be included as external costs that are born by society. In recent educational material (published in Polish) a colleague and I [Chruszczow, Mitroczuk 2022] examined the cost relations of various energy sources, in a simplified model based on PEP 2040 data. We realise, of course, that the data for PEP 2040 were taken from 2018 (at best). But this analysis tries to compare them with older data on external costs (2008–2030). To show their influence on LCOE, we can look at future estimates (2030), as a necessary signal for the need to cope with society-wide externalities for the use of fossil fuels. The decisions taken today will influence the energy mix we use for decades to come. The whole modelling is based on cost calculations combining LCOE (based on PEP 2040) and external costs (based on the literature). The starting point is 2019 and it takes the existing capacity of a given source and calculates how many new GW of source capacity would need to be added to the electro-energy mix. To make the model simple, it is assumed that we would need to make an investment decision now, to be able to safely utilise 200 TWh (terawatt hours) of energy in 2040 from the given source. That is, a high penetration of all of the sources is assumed in order to allow for comparisons – which is verified in the last section where an alternative mix is presented – with proposed percentages of the mix. It is a simple investment model in which the average cost per MWh is calculated (adding investment cost, fixed costs and variable costs as well as external costs such as environmental and health-related costs for fossil fuels, as well as network, profile, and grid-balancing costs for all RES) of power provided by a specific source of energy. The data on the Annual Average Power Utilization Factor (CF) and the data on the durability of a given source were collected on the basis of PEP 2040 [Monitor Polski 2020].

Social costs have been calculated by adding to LCOE (private costs), the external costs (born by society) associated with the detrimental influences of using fossil fuels for energy on human health, on the environment, on crops, and those detrimental events and conditions related to the consequences of climate change. In this paper the calculations that group the costs of GHG emissions, NH_3, NO_X, and SO_2, as well as PM emission-associated costs as external costs are calculated. They were found to be at the level of 35 EUR/MWh (2008) and 55 EUR/MWh (2030) for hard coal CHP and 15 EUR/MWh (2008) to 22 EUR/MWh (2030) for gas turbine [Preiss et al. 2008]. Other research puts them at comparable levels of 40 EUR/MWh (2012) for coal and 20 EUR/MWh (2012) for gas [D'haeseleer 2013]. In the calculations based on the simple excel model, I took a moderate level of external costs to be 50 EUR/MWh for coal and 20 EUR/MWh for gas-powered sources.

The GHG emission costs of ETS, which from the point of view of a company in the system are private costs, should in theory produce such result that would internalise negative externalities (compare previous section). They are treated as private costs in CAKE modelling [Tatarewicz et al. 2022]. I decided not to include them in the cost scenario but to follow the path of inclusion of external costs to energy generation, which are born by society. Including both the ETS (as private cost of energy companies) and external costs (social costs borne by society) would mean that some part of the costs associated with CO_2 emissions that are covered by ETS, would be calculated two times, pushing fossil fuels down, as much less competitive, from the viewpoint of LCOE+.

The possible costs of nuclear disasters as well as RES network costs are included in the model as proposed by D'haeseleer in his report to the European Commission [D'haeseleer 2013], adjusted by newer data from OECD countries [Karkour et al. 2020]. In regard to RES, I take into account the balancing, network, and profile costs of these sources, assuming their high share in the energy mix, which results in high values being added to the total LCOE+ as presented in Figure 2. I wanted to clearly show that the development of RES also involves substantial external costs, which are mentioned less frequently. For more details about those, see [Chruszczow, Mitroczuk 2022]. The environmental costs for nuclear energy were assumed to be at a maximum of EUR 7/MWh, including possible accidents [D'haeseleer 2013]. The results are meant to show the public that the long-run scenario for Poland could be based even more on RES complemented by fossil fuels, than the scenario presented in the PEP 2040. In that, my results do not differ much with that of the CAKE project [Tatarewicz et al. 2022].

I skipped the interest rate calculations to avoid the difficult discussion about what they might be, after the pandemic recovery and the inflationary pressures we are observing now. Also, all the calculations were done before the war in Ukraine, which changed the level of prices and made gas a less viable solution due to the increased importance of security considerations, but I still treat that as a short-term disequilibrium, which does not exclude the use of gas (especially in cogeneration) in the medium term. The numerous simplifying assumptions make the model basic, but still allow us to draw policy recommendations. The long-term changes in the cost levels dynamics (both LCOE and external) between the different sources of energy and the new climate conditions will be elaborated upon in my future work.

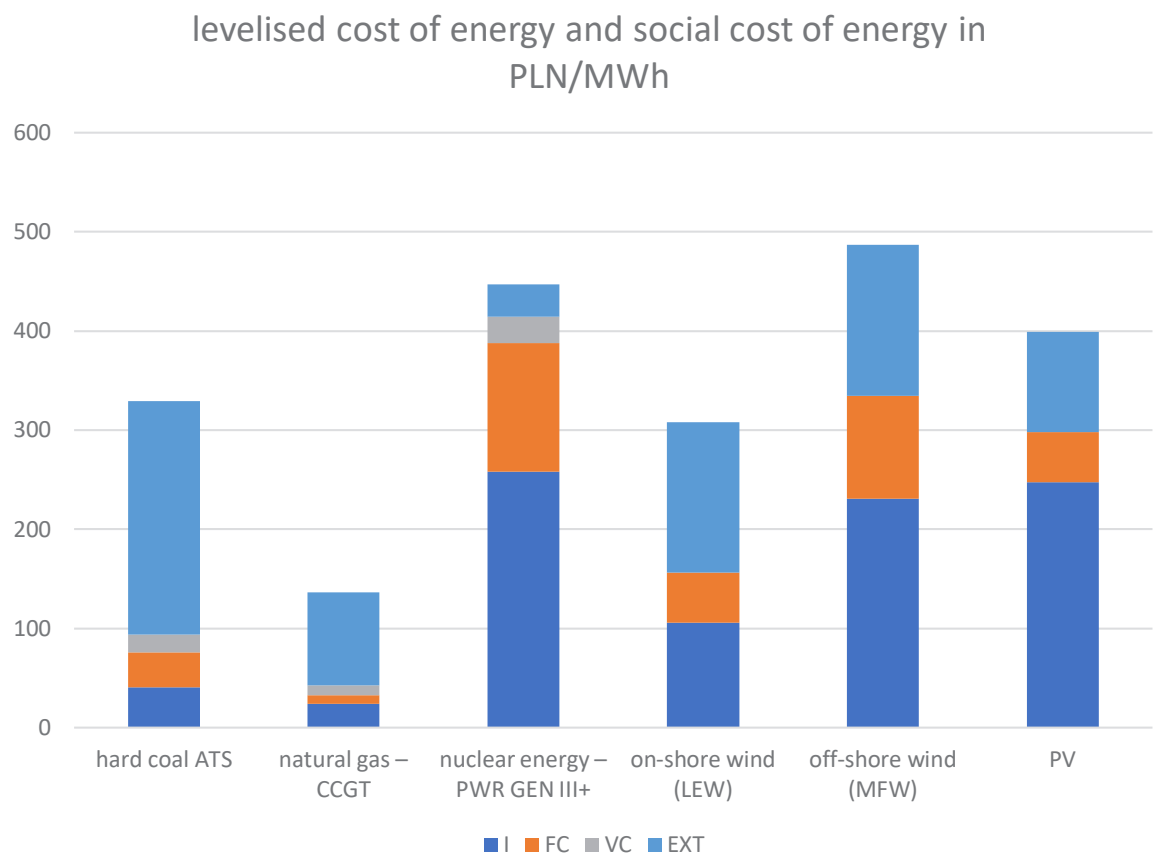


Figure 2. Comparison of the total costs of production in PLN per MWh of energy.
Source: The author's own calculations on the basis of cost data of PEP 2040.

I	Investment costs based on PEP 2040
FC	Fixed costs based on PEP 2040
VC	Variable costs based on PEP 2040
EXT	External costs based on sources mentioned in the text

This analysis is limited to six main energy sources that together constitute 95 percent of the 2040 energy mix, according to the national strategy PEP 2040. It follows the cost of (1) hard coal power plants – ASC PC[1]. It then follows (2) natural gas power generation or CCGT, described in the policy as an intermediary and medium-term substitute for coal, necessary to guarantee the stability of the system, coupled with a growing share of renewable sources and with the necessary base of the future energy mix being (3) nuclear energy – assumed after PEP 2040 to be PWR GEN III+. In addition, the analysis includes the three most important renewable sources: (1) on-shore wind (LEW), (2) off-shore wind (MFW), and (3) photovoltaics (PV), the last source being successfully developed by individual prosumers, at record speed of 1100 percent increase of number of Polish prosumers from just 4,000 in 2015 to 0.5 million in 2021 and 1 million expected by 2030 [Kurtyka 2021]. The process was enabled by initially generous financial support from the government and growing social consciousness about environmental and energy issues.

The calculations I ran compare sources as though each of them was to deliver the entire demand for energy consumption (200 TWh), which is only a theoretical figure. I do it this way in order to guarantee a high penetration of the source in the energy mix, to cover the costs associated with that high penetration (especially costs associated with grid stability, balancing, and profile costs of the grid under conditions of high penetration by renewables). Those costs can be particularly important as the Polish

1 It is believed that lignite could be eliminated from the mix by rising ETS costs (see last section) as well as growing ecological consciousness of the Polish society, coupled with the supply shortages and limited supply available at reasonable costs.

grid is in need of a high maintenance and development investment.
In the simple excel-based model, I assumed the durability of atomic sources to be 60 years with 10 years of construction time [Wealer et al. 2019], the coal and gas plants' durability to be 35 years, and the renewable sources durability to be 20 years, after data from PEP 2040 [Monitor Polski 2020].

4. RESULTS OF THE SIMPLE LCOE+ MODEL

The following graph shows the adjusted results of the cost analysis as described in the previous section.
These calculations will not change with the growing cost of EU ETS, which is not added to private cost and which are implemented to make fossil fuels less competitive in the energy mix. New calculations of external costs could follow with more accurate health and environmental costs data. That will make fossil fuels even less competitive. Still, they will be necessary for grid-balancing purposes. Alternatively, this can be achieved by a mixture of gas-powered sources and also by nuclear energy, working in the base of the energy system.
The price of emissions has grown rapidly from EUR 8 to over EUR 35 in 2020 and almost EUR 100 in 2022. Experts show that by 2030 they can reach a level of between EUR 75 and 100 [Jeszke 2021]. On the other hand, if the trends shown by the Lazard analysis Lazard are to continue [Lazard 2020], we will probably face further decreases in the investment costs for PV as well as for wind power, both on- and off-shore, leading to even more creative solutions for the possibilities around which the Polish energy mix could be shaped to fit for the 'Fit-for-55' package, after necessary pro-security and pro-solidarity modifications.
Having analysed the alternative costs of production of 1 MWh of energy from a given source (see Figure 2), where costs include investment costs, fixed and variable costs of the source as well as external and grid-related costs of sources, I will describe a simple scenario analysis comparing how we can shape the energy mix in order to deliver 200 TWh of energy in 2040.

5. THE CONSERVATIVE SCENARIO – PEP 2040

On 2 February 2021, the Council of Ministers approved Poland's Energy Policy 2040 (PEP2040). A document that presents a vision of transformation of the energy sector on the path between the need to get to climate neutrality, in line with the role of the European Union as the prime-league player in a global match against climate change, and a compromise, respecting national circumstances (we have the largest deposits of hard coal in European Union and tend to treat that as the national energy security guarantee). That obviously is a scenario full of challenges, with the first one being the speed of the energy transformation enforced by the European Union.
According to the document coal use will be reduced considerably. This will translate into a reduction of the use of coal to a level not exceeding 56 percent in electricity generation in 2030 from 74 percent in 2019, and 95 percent in the early nineties. The special circumstances of the energy transformation are also complicated by the fact that the Polish energy sector is based mainly on seriously worn-out coal-fired power plants. All that translates into a plan proposing that by 2040, about 16 GW of coal-fired capacity could be withdrawn from the national grid and substituted with other energy sources. This also applies to the heating of individual houses to a significant extent, where the government, by direct subsidies, is trying hard to speed up the process of renewal of old and inefficient heaters in individual households.
The phasing out of old capacities and the constant growth of demand for energy (both electricity and heating/cooling) means an urgent need for building an entirely new energy system. This is an opportunity; that is, we can shift from low-efficiency fossil-fuels to high-efficiency renewables, but it also constitutes a challenge – how to do it in an economically viable way and also in a fair and just way. That means at least two things. The first challenge is the need to halt the spread of energy poverty among Polish households, which is already at one of the highest rates in the EU. A study that shows an analysis of the two important energy and climate policy instruments, renewable energy policy and the EU ETS, shows how the policy of providing numerous industry exemptions to contributing to the cost of renewable energy policy the emissions-trading scheme were spreading, thus leading to individual households bearing most of the costs associated with those policies. The analysis also shows that low-income households are the most affected by the price increase, because they tend to spend a large proportion of income on electricity [Cludius 2015]. And indeed, in Poland our households tend to spend a large proportion of the consumption-spending budget on energy. Analysis shows that introducing changes suggested in 'Fit-for-55' would increase spending on housing energy by 50 percent and spending on transport by 44 percent for one-fifth of the poorest households in the EU. In the case of Poland, that increase would be even higher standing at 108 percent [PIE 2021].
The second challenge is to limit social unrest during the process of restructuring the coal mining sector in Poland, which plays an extensive social role, providing employment to nearly 80,000 people, concentrated in mining regions of the country and represented by traditionally strong and well-organised trade unions used to protesting in a raw way on the streets of the capital. The only government that was brave enough to limit the coal-mining employment by 100,000 and, according to the ex-Minister of Economy, Janusz Steinhoff, 'saved the Polish mining' [WNP 2009] was the government led by Jerzy Buzek. The position of coal in the Polish energy mix is determined not only by the fact of the Polish EU membership, but also because some coal-burning power plants will have to be closed because they are old, fully utilised in technical terms, and

inefficient, and because they cannot be in continuous operation when competing with the cheaper alternatives on the market [Gawlikowska-Fyk 2021]. More than 70 percent of the coal-burning power plants are more than 30 years old and are just approaching the limit of technical viability – the average age of power plants in Poland is 47 years [Kurtyka 2021] and URE is predicting the retirement of some 11 GW of power in coal-burning facilities by the year 2034 [Wysokie Napięcie 2022]. From 90 electro-power units running on hard coal and lignite, 70 are already beyond the retirement date. The number of breaks in their operations is steadily growing year by year, and in 2017 was at the level of 27K hours. [Forum Energii 2019]. The reduction in employment in the near future would not be dramatic if it were accompanied by real modernisation of the mining sector leading to increased efficiency. But that has not been happening, according to the ex-vice-minister of Economy Jerzy Markowski [WNP 2022].

The transformation of the energy mix will require not only the deep transformation of the electricity generation sector, but also a rapid increase in the use of renewable energy technologies in heating/cooling generation and an increase in the use of alternative fuels in transport. The heating sector will also reduce the use of coal, this applies especially to the heating of individual houses. The use of coal in households should be phased out by 2040. 'Dirty fuels' will be replaced by low-emission renewable sources like heat pumps, natural gas, low-emission systemic central heating, and electric heating. The use of unabated coal will also decrease in the heating sector as a result of the assumed increase in energy efficiency, the development of higher-efficiency co-generation, and the process of adapting to the EU regulations. It will embrace the requirements of the directive on the energy performance of buildings (EPBD), as it forces limitation of the use of fossil fuels, and according to the RED II Directive, the share of renewable energy sources in the consumption of heat and cooling should increase by 1.1–1.3 pp *per annum* in the years 2021–2030. For this reason, it is expected that the share of renewable sources in the consumption of heat and cooling will amount to 28 percent by 2030. We should also remember that activities related to the increase in the use of renewable energy sources in Poland are partly due to the increased social pressure on improving air quality. The majority of Polish citizens (over 90 percent) agree that we should limit the greenhouse gas (GHG) emissions, and 60 percent agree that we should act today, rather than some unknown tomorrow [MKiŚ 2020].

A deep reduction of GHG emissions and pollution will also be possible in transport, through the development of electromobility, hydro-mobility and the widespread use of zero-emission public transport in all bigger (more than 100,000 population) Polish cities. City transport is taking the lead in the process, and individual transport is lagging behind; e-car registrations are still only around 2 percent of the whole [Monitor Polski 2020]. Increasing the use of electric cars might be another difficult challenge to overcome.

The Polish energy strategy assumes that the transformation of the new energy system will be carried out slowly in order to guarantee stability of energy supplies and swift management of the relatively old power grid, endangered by the unstable renewable energy sources that are growing rapidly. The programme provides for massive investments in both on-shore and off-shore wind farms and PV plants, as well as in nuclear energy. At the same time, effective and fully disposable gas units, which are to constitute a supplemental and vital reserve for renewable sources dependent on weather conditions, will be utilised within a transitional period of energy transformation. They should fade away as the use of large-scale energy storage and better power grid management systems become economically viable. It is assumed that the total installed capacity of renewably sourced electricity generation units will amount to some 23–25 GW in 2030, resulting in a doubling of the installed RES capacity compared to 2020, allowing for the generation of up to 32 percent net electricity in 2030.

Most important for the transformation efforts will be investments in the development of offshore wind farms – a 5.9 GW will be installed in 2030 and an 8–11 GW in 2040, followed by solar power plants, with some 5–7 GW capacity wind farms installed in 2030 and even 10–16 GW in 2040. The first nuclear unit with a capacity of 1–1.6 GW is scheduled for 2033, and the Polish nuclear power programme provides for the construction of some 6–9 GW by 2043. The power balance assumed in the PEP2040 programme is to maintain energy security with demand growing to 200 TWh of energy used in 2040 [Monitor Polski 2020].

Energy transformation cost for Poland is estimated at an enormous PLN 1.6 billion during period from 2021 to 2040 [Monitor Polski 2020] and even higher at PLN 2.3 billion according to the estimates of the Ministry of Climate and Environment in Poland from 2020. We need to note that the programme was prepared and approved before the European Commission revealed its plans for the 'Fit for 55' package presented in July 2021 and will have to be amended to match the higher ambitions of the Union. The European Green Deal and REPowerEU both require a deep digital and sustainable transformation of our energy mix. They envisage installation of solar photovoltaic panels on the roofs of all commercial and public buildings by the year 2027 and on all new residential buildings by 2029 [EU 2022a] and also installation of 10 million heat pumps over the next 5 years [EU 2022b]. That will increase the amount that needs to be invested, which might constitute the biggest challenge of all – how to finance the transformation without huge increases of costs of energy to industry and to individual households. Therefore, it is crucial to make wise decisions on how and what for the money will be invested – an ideal question for economists and politicians to ask.

One option for Poland would be to follow the solutions adopted for the future of the energy mix as presented in the National Energy Programme PEP 2040 (see Figure 3).

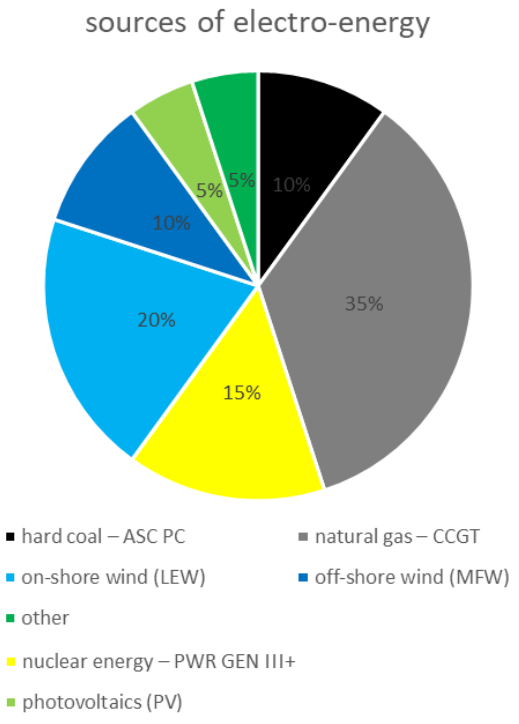


Figure 3. The electro-energy mix of Poland 2040.
Source: The author's own calculations based on PEP 2040.

6. AN ALTERNATIVE SCENARIO

In the previous analysis, I demonstrated that the alternative energy mix can be cheaper to society if the total costs and effects of the transition are accounted for [Chruszczow, Mitroczuk 2022]. Here, I show the two alternatives: one without nuclear energy and the second with its utilisation as a complementary source to gas, to stabilise the base of energy mix. Alternative scenario one is based on just four energy sources – the broad base of gas power (in cogeneration), followed by large on-shore wind farms, with 15 percent of more expensive off-shore wind and just 5 percent of PVs. That is complemented by other RE sources, like biomass and hydro/geothermal energy, as also proposed by CAKE [Tatarewicz et al. 2022].
The second alternative scenario, more in line with the longer-term cost relations [Lazard 2020] and including nuclear energy as a necessary component is the following: 30 percent gas, 10 percent stable nuclear power, 30 percent on-shore wind, 10 percent off-shore wind, and 10 percent photovoltaics, with 5 percent reserved for other RE sources. Both scenarios are based on an assumption of complete withdrawal from coal as an energy source (difficult to imagine today due to political and social reasons, as well as to increasing energy prices, which I believe are a short-term disruption due to the war in Ukraine) and the necessity of considering strongly politically driven plans for the development of nuclear energy (exclusion of nuclear is also difficult to imagine nowadays, but not impossible).

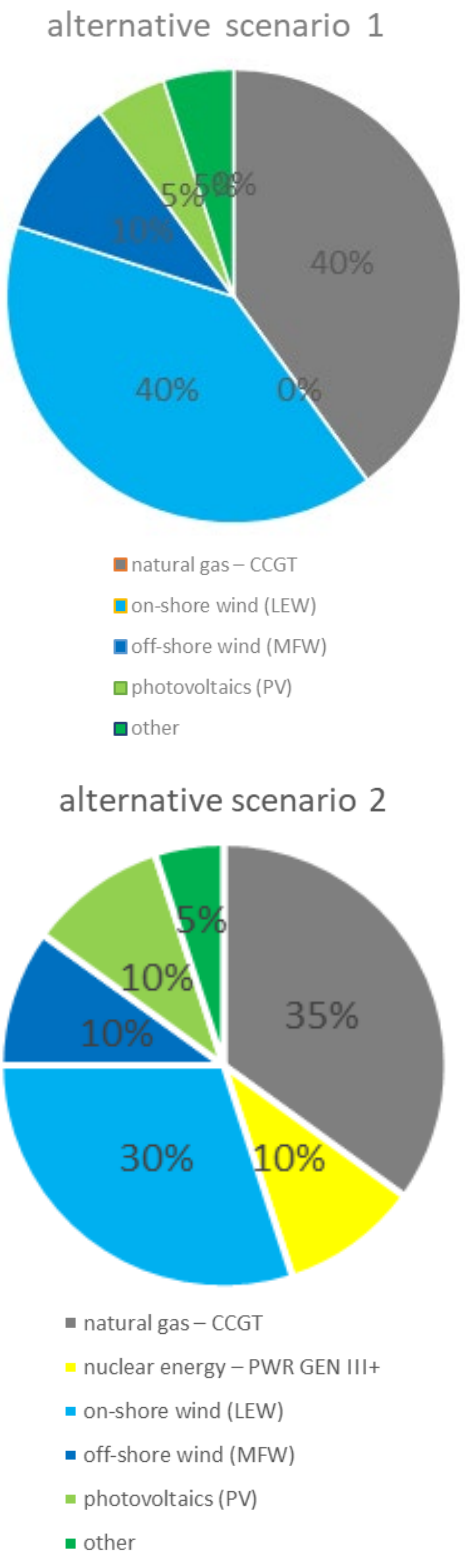


Figure 4. Alternative 2040 electro-energy mix for Poland.
Source: The author's own calculations and adaptation of [Chruszczow, Mitroczuk 2022].

When considering the total cost of proposed energy-mix transformation for society, including the social cost of a given mix, both are much cheaper than the base PEP 2040 scenario above. Scenario one has a 10 percent lower overall cost to society and scenario two has a 20 percent lower overall cost.

In that analysis, I assumed that the facts – deterioration of human health due to worsening air quality as a result of burning fossil fuels, the growing pressures from the EU (not only the ETS prices but the 'Fit-for-55' package and the entire Climate Law in preparation) – will force the change. Moreover, both alternative scenarios presented, without discussing which is better and why at this stage, are in line if not well above the line, with the aims of the 'Fit-for-55' package of the European Commission, which encompasses revision of the RES directive [Chojnacki 2021].

7. CONCLUSIONS

The purpose of this article was not to suggest a ready-to-use energy mix for Poland. I feel I need to do much more research in that area in order to deliver more elaborated advice. My plan for further research is to first analyse other countries' experiences and also to follow Polish discussions about coal and RES, as the two main alternatives that I plan to address in the last article of this series. It is difficult today to imagine that Poland will start tomorrow to follow the alternative scenario one as presented above. I can only hope that the necessary revision of the Polish Energy Programme PEP 2040, in view of the new scenarios written in Brussels, will be closer to it.

One dimension that I did not analyse was the social costs of coal mine restructuring (definite closure before 2049, which was the year for completing the transformation officially agreed upon with the coal mining unions). It is true that looking at the LCOE alone, and not taking into account environmental and health-related social costs, domestic and imported coal is relatively cheap and ready to be used as an alternative to imported gas, not to mention renewables. That is why both Poland and Germany turned to lignite and hard coal as a result of the market disruption caused by war and speculation [Forum Energii 2022]. Nevertheless, that approach, short-term, excludes external costs from consideration in the decision-making process.

Whatever approach the Polish energy transformation follows will depend not only on the final results of the 'Fit-for-55' legislative package, but also on the political processes in the country. Both are not clear now. And the war in Ukraine has added a completely new perspective on energy security, which is at the forefront of the considerations. When energy security matters so much in the new geopolitical situation, it is hard to imagine that the electro-energy mix could be composed without nuclear energy. One possible option that I want to discuss in a future article is a distributed electricity generation model and a wide use of self-sufficient prosumer solutions, not only for individual houses but also in industry, where RES/SMR (small modular reactors)/HTGR (high-temperature gas-cooled reactors) technology could help, provided its capital expenditure (CAPEX) goes down. Changing energy and heating prices as well as possible blackouts in the medium term can demonstrate that is a viable option. Another important aspect of my future analysis should be energy efficiency – the cheapest source of energy of all is the energy you don't use.

My small input into this discussion of utmost importance for the future capabilities of Poland to compete in international markets suggests making some calculations before we embark on a massive investment programme that will leave us with a new fixed structure for the energy mix for decades to come. The economic model described in the first section of this article suggests that if you make a change – in our case unavoidable for many reasons, not just EU membership – we should choose the way that will provide for the maximum net gain for the society. The way is very simple – as an economics model can be – abandon the most polluting and dirty sources - with high negative external costs, towards clean ones, with quickly falling LCOEs, that is, RES. Ideally, we should try to manage the transformation process, with maximum net gain for the labour market, and the renewables meet those criteria.

Today, the price of electricity with delivery for the next year has increased to PLN 1,635/MWh, compared to PLN 360/MWh that was paid 12 months before. This is the highest price ever paid in Poland for an energy supply contract for the next year. It is still moderate when compared with rates across Europe, and my price calculations may seem outdated [Derski 2022]. I would like to stress the purpose one more time – long-run analysis in economics should be separated from short-term shocks. Economists' analysis, especially when looking at the very high disproportions (157 percent) in European prices for the next year, largely due to the large differences in energy mix of those countries, is an interesting subject for analysis in itself.

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