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Modeling the Green Transition in the European Union: An Organic Market-Oriented Perspective

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ABSTRACT:
In the context created by the short-term energy market disruptions generated by the war in Ukraine and the longer-term concern for achieving a climate-neutral continent by 2050, the European Commission issued, in May 2022, the REPowerEU plan aiming to reduce significantly the dependence on fossil-based energy sources by 2027. Despite the increasing employment of renewables, the green transition faced important challenges and did not generate results consistent with the proposed objectives.
The nature of the transitional process explains the gap between objectives and results suggesting that an organic transition to clean sources of energy could be a more effective strategy allowing a gradual reduction of the share of the still important conventional sources in energy production and final consumption and their corresponding balanced replacement with renewables ones.
The paper presents the results of an exploratory assessment based on the secondary data and from a market-oriented perspective of the evolution of final energy consumption and energy production structures, weighing the shares of renewables and conventional energy in the last three decades, regarded as the background of the future modeling attempts, in connection to the relevant economic, social, and environmental dimensions of the sustainable development in the EU Member States.

Keywords: Green transition, Renewable energy, Energy market, European Union, Sustainable development

1. Introduction

Approaching the challenges of global warming, climate change, and environmental pollution, the European Union advanced in 2019 the European Green Deal, aiming to reduce net greenhouse gas emissions to zero by 2050, making society competitive and resource-efficient (European Commission, 2019a). The context created by the war in Ukraine has demanded the adoption and implementation of measures to reduce dependency on energy imports by accelerating the energy transition to a climate-neutral economy based on massive deployment of renewable energy – seen as the key element of the European Commission's REPowerEU plan – aiming, by 2030, a share of 45 % in the energy production (Dekanozishvili, 2023).

Green energy has been regarded as a sustainable solution to the socio-economic and environmental issues, including the depletion of non-renewable energy sources, the employment of renewables at the expense of conventional sources, generating a positive impact on climate change, global warming, and carbon dioxide emission reduction (Kumar

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et al., 2023). According to Dincer and Rosen (2011), green energy is the form and use of energy that has no or minimal negative impact on the environment, economy, and society and includes solar, hydropower, biomass, wind, geothermal, and other renewable sources, providing an important option for meeting the demand for clean energy and, consequently, being a major factor for future sustainable development and global stability. Midilli et al. (2006) observed that green energy is more environmentally benign ensuring global stability by reducing the harmful effects of fossil-based energy and recommending a transition to a green energy economy powered by investments in dedicated technologies.

Besides green energy, the literature also uses the concept of clean energy. Alternatively using the terms green and clean to describe and represent renewable energy sources, Keramitsoglou et al. (2016) identify a rather chromatic, yet imprecise understanding of the term explaining that green energy probably refers to the growth of vegetated areas due to the reduction of air pollution, with beneficial effects on seas, desert areas, and wildlife; but energy does not look green, that is why term clean may be more appropriate to represent renewable energy sources. Zohuri et al. (2022) define renewable or clean energy as a type of energy coming from natural sources or processes, that is constantly replenished and is expected to become the main solution for climate change. Chandel et al. (2024) have pointed out that green energy comes directly from natural sources such as the sun, wind, and geothermal heat, while clean energy is the type of energy where no pollutants or contaminants are released into the environment. The statistical data illustrate the growth of clean energy in recent years as a result of strong policy support and continuous decline in costs: at the global level, clean energy investment increased by nearly 50 % between 2019 and 2023, by an annual average rate of 10 %, reaching $1800 billion in 2023 (International Energy Agency, 2024).

Approaching the shift from fossil-based fuels to a non-fossil world as a fundamental process of the evolution of human societies, driving and driven by technical, economic, and social changes, Smil (2010) has defined energy transition as encompassing the time that elapses between the introduction of a new primary energy source (coal, oil, nuclear electricity, wind captured by large turbines) and its rise to claiming a substantial share of the overall market. The transition to renewable energy sources, accompanied by conservation efforts, reduced consumption, increased reutilization, and recycling is needed to compensate for environmental damage, reduced biodiversity, diminishing natural resources, and even displacing local communities caused by the use of fossil fuels (Wang and Azam, 2024).

Rodríguez-Pose and Bartalucci (2023) have identified direct (associated with carbon emissions from fossil fuels and reliance on brown energy, especially coal) and indirect (the resulting shocks and transformations linked to productive, regulatory, and behavioral shifts) impacts of the green transition, its implementation requiring enhancing the resilience of supply chains and maintaining the competitiveness of businesses and products in compliance with the environmental requirements (Palieri, 2024).

Rabbi et al. (2022) considered that energy transition is viable by searching for alternative sources of clean energy supply, saving energy, and generating renewable energy, thus providing quality benefits for consumers' everyday lives. Macedo and Marques (2023) connected the energy transition to higher public spending on technological innovation in renewable sources through research and development and lower spending on flexible

fossil-based sources suggesting that this approach may generate higher invoices and increasingly dissatisfy users compared to extensive and less risky research and development on fossil fuels susceptible to produce higher returns reflected in relatively affordable prices for energy consumers. Green energy has an economic impact reflected in more jobs, lower consumer costs, universal access to energy, attractive investment for investors, and reduced disaster recovery and reconstruction costs (Dublino, 2023). Linking green energy and the economy, Braga and Ernst (2023) advanced the idea that the transition to a green economy requires significant resources, from both private investors and public policymakers, impacting the labor market and living standards and being accompanied by large social, economic, and political transformations mandatorily to be factored.

Taking into consideration the dimensions of sustainable development, Akella et al. (2009) have concluded that using renewable energy creates social (improved health, increased consumer choice, greater self-reliance, work opportunities, technological advances), environmental (reduced air pollution, lower greenhouse gas emissions, lower impact on watersheds, reduced transportation of energy resources and maintaining natural resources for the long term), and economic (job creation, economic activity in other sectors, reduced fuel consumption or electricity bills, more ways to generate revenue).

In the European Union, the green transition is seen as an opportunity to create jobs, an engine for environmental sustainability (Urban et al., 2023), with significant impacts on gross domestic product, investment, employment, competitiveness, distribution, public finances, and monetary stability (Erbach et al., 2022). There are several priorities associated with the process, such as emission reductions, promotion of sustainable energy systems, innovation in clean technologies allowing lowering the costs of alternative sources of energy and economic growth, strengthening the companies' competitiveness, fostering innovation performance, and supporting overall sustainable development (Conti et al., 2018).

The solution proposed by Potrč et al. (2021) for a sustainable, efficient, competitive, and secure EU energy system is a stepwise energy transition achieving a carbon net neutral target by 2050 by producing a supply of renewable electricity, biofuels, hydrogen, and bioproducts from different renewable sources, directly interacting with the food supply network, accompanied by a gradual transition to renewable energy production in the transport and electricity sectors, with the wind being the key technology in the first years and solar photovoltaic expanding after 2030 due to improvements in economic performance.

Exploring the extent renewables can gradually replace fossil fuels by 2050, Holechek et al. (2022) identified eight transition pathways: renewable energy development, improving energy efficiency, increasing energy conservation, carbon taxes, more equitable balance of human well-being and per capita energy use, cap and trade systems, carbon capture, utilization, and storage, and nuclear power development.

According to the European Parliament (2022), the energy transition should create a wide range of benefits for European consumers (cleaner air, water, and soil, reduced energy bills, renovated homes, better public transport and more charging stations for e-cars, less waste, healthier food, and better health) and businesses (new opportunities and new jobs created in renewable energy related areas). Observing how the European Green Deal has been designed, Barbieri et al. (2021) expect as outcomes a cleaner environment

due to increasing energy efficiency, clean energy production, waste reduction, and improved agricultural practices, as well as better population health, improved transport alternatives, access to distributed electricity generation options, better access to more modern and resilient services. Yet, the European Green Deal affected the business environment due to the prioritization of the environmental dimension, offering the government opportunities to intervene through fiscal policies and other administrative instruments, distorting entrepreneurship and competition in the market (Bogoslov et al., 2022). As businesses have a responsibility to prevent, reduce, and minimize environmental damage to water, soil, and air, and solve waste, pollution, and resource consumption problems (Lamenta and Grzybowska, 2023), the implementation of the European Green Deal will impact the carbon-intensive energy companies by altering their business model, fading their competitive advantages and switching the investments in business lines consistent with long-term climate policy objectives (Rybski, 2023).

2. Methodological notes

The exploratory analysis of the European Union energy sector was conducted using aggregate indicators selected from the new methodology proposed by Eurostat (2023) to assess energy balance. Our main goal has been to explore final energy consumption in terms referring to the main final consumers, the energy sources used to supply their consumption, and the associations between final consumption, primary production, and specific imports and exports.

Although we acknowledge the overall efforts to produce and distribute energy involving significant amounts of natural, technological, financial, and, last but not least, human resources, we have resisted the temptation to begin our research with the market's supply side. Under a marketing approach, the starting point of the research and following discussion must be represented by the demand side – the final consumption of the products and/or services delivered in the market.

The final energy consumption is the first research variable that, according to the Eurostat methodology, includes the total energy reaching the final consumer's door and employed by end users, such as industry, transport, residential, commerce and public services, agriculture, fisheries, and the remaining sectors. We did not take into consideration the final non-energy consumption (accounting for 6.50 % of the total energy supply), distribution losses (1.59 %), energy (4.86 %), and transformation (23.30 %). Just a remark about this last sector including the input and output of energy used in electricity and heat generation, coke ovens, blast furnaces, gas works, refineries and petrochemical industry, patent fuel, brown coal and peat briquette, charcoal production, coal liquefaction, and gas-to-liquid plants, blended natural gas, liquid biofuels blended, and not elsewhere specified: as, on the one hand, it weighs almost a quarter of the total energy supply and, on the other hand, it is a constant generator of losses, transformation could represent one of the areas where improvements in terms of are not only expected but desired.

Putting in the balance the supply side, our approach has been considered as research variables: primary production of energy (defined as the total energy products extracted from natural sources such as coal mines, crude oil fields, hydropower plants, biofuels production capacity, etc.) and delivered in usable forms (coal, oil, natural gas etc.);

energy imports (defined as the total energy products imported in usable forms – coal, oil, natural gas, etc.); energy exports (defined as the total energy products extracted from natural sources such as coal mines, crude oil fields, hydropower plants, biofuels production capacity, etc., and exported in usable forms – coal, oil, natural gas, etc.); finally, gross available energy (defined as the overall supply of energy necessary to satisfy all the energy demands on the territory of the European Union and each of the Member States) including, for the purpose of our research production, imports, and exports without recovered and recycled products and stock changes (that represented, in average, only 0.13 % in the total of gross available energy).

Secondary data regarding final energy consumption, primary production, imports, exports, and gross available energy at the level of the European Union provided by Eurostat and the European Commission have been employed to determine and assess the average annual variation and dynamics of the considered variables. To ensure a common analytical ground and avoid the potential distortions generated by the EU extension and Brexit, the data referring to the energy sector have covered the 27 Member States as of the end of 2022.

3. Main findings

During the analyzed period, the **final energy consumption** in the European Union has fluctuated, alternating ups and downs that have generated an extremely slight negative annual variation (-.014 %), the consumption decreasing from 906.47 to 902.15 Mtoe.

The European Union has three major consumers – industry, transport, and residential – accounting for more than 80 % (an average of 83.49 % between 1990 and 2022) of the final energy consumption. Together with the commercial and public services, their weight surpasses 95 %, (an average of 96.15 % between 1990 and 2022), the difference up to 100 percent corresponding to agriculture, fishing, and other sectors. The analysis has identified several trends regarding the share of the major users in the total final energy consumption: (a) decline of the industry, by an annual average rate of -.98 %, from 34.23 (1990) to 25.08 % (2022), respectively from 310.27 to 226.25 Mtoe; (b) growth of the transport and commercial and public services, by an annual average rate of 0.74 %, from 10.46 (1990) to 13.45 % (2022), corresponding to 220.70 and 279.89 Mtoe, respectively an annual average rate of 0.77 %, from 24.35 % (1990) to 31.02 % (2022), corresponding to 94.78 and 121.32 Mtoe; (c) stability of the residential sector (private households), due to the extremely slightly annual average increase of only 0.03 %, from 26.46 % (1990) to 26.88 % (2022), corresponding to 239.83 and 242.49 Mtoe.

Transport has become the major final energy consumer, and oil is by far the most important energy source, accounting for 94.01 % of the overall energy supply of the sector. Still, it is remarkable the growth of other sources such as renewables (with an annual average rate of 26.12 %), natural gas (7.29 %), and electricity (0.35 %). Although their cumulated share remains low, with renewables accounting for two-thirds, the dynamic of their expansion, which has allowed an almost fourfold growth – from 2.37 (1990) to 9.11 % (2022) suggests notable, yet challengeable prospects. The share of oil imports and, consequently, the dependence on imports, represents a real challenge for any attempts to

manage the green transition.

Residential has surpassed Industry, becoming the second major final energy consumer in the European Union. By comparison to Transport, the energy consumed by private households comes from a more diversified mix of sources, which has experienced changes in the analyzed period. In 1990, oil was the most important energy source (accounting for 24.30 % of the total consumption), followed by natural gas (23.53 %) and electricity (18.45 %), and accompanied at a significant distance by heat (11.46 %), solid fuels (11.35 %), and renewables (9.62 %). In 2022, natural gas replaced oil as the most important energy source (accounting for 30.89 % of the total consumption), followed by electricity (25.10 %) and renewables (22.64 %), with oil (10.88 %) and heat (8.15 %) completing the hierarchy at a substantial distance. The remarkable ascendance of renewables has compensated for the abrupt decline of the solid fuels lowering to only 2.26 % in 2022 and transforming into a rather peripheral energy source. As in Transport, imports, in this case of natural gas, and the corresponding dependence, represent an important challenge in managing the green transition in connection to this major final energy consumer.

The Industry has lost its second position to remain the third final energy consumer at the European Union level. In 1990, natural gas and electricity represented the main energy sources weighing more than half (52.80 %) in the sector's total consumption (28.06 % - natural gas, and 24.74 % - electricity), while in 2022, the same duo consolidated their position weighting for almost two-thirds (64.53 %) in the total consumption of the sector yet exchanging their places (33.28 % - electricity, and 31.25 % - natural gas). Oil remained the third source but has decreased in terms of share from 17.61 % (1990) to 10.82 % (2022), while renewables enlarged their contribution from 4.20 (1990) to 10.64 % (2022), replacing a continuously decreasing solid fuels (from 14.30 %, in 1990, to only 4.32 % in 2022). Heat (6.49 %, respectively 5.62 %) and other sources (4.59 %, respectively 4.07 %) maintained their peripheral positions during the analyzed period. As in the case of residential, the imports of natural gas share represent a vulnerability to be considered in planning and implementing the green transition.

Commercial and public services represent a less important, but relevant (in economic and social terms) segment of final energy consumers, which has experienced a relatively similar evolution to the residential sector. Electricity and natural gas were and still are the main sources ensuring the energy consumption of the sector their cumulated weight increasing from 55.45 % (1990) to 77.47 % (2022). Between 1990 and 2022, both have registered increases in terms of weight, more impressive for electricity - from 33.86 % to 50.55 %, respectively from 21.59 % to 26.92 % for natural gas. Oil has dramatically diminished its share from 25.30 % to only 6.31 % coming below increasing renewables (from 0.59 % to 8.00 %) and heat (from 5.06 % to 7.59 %), while solid fuels registered the most abrupt decline (from 12.64 % to only 0.35 %).

Analysis of the final consumption in terms of the structure of the sources employed to generate energy revealed four trends of evolution: first, a similar and statistically significant associated evolution only in the case of natural gas ($r=.839$, $p<.01$); second, a similar but not statistically significant associated evolution – registered by oil ($r=.486$), electricity ($r=.478$), and heat ($r=.474$); third, an opposite and not statistically significant similar evolution – registered by other sources ($r=-.439$) and solid fuels ($r=-$

.201); finally, a fourth particular, basically disruptive, evolution with no connection to the overall final consumption – renewables (r=-.040). This diversity of trends regarding the sources employed to supply the final energy consumption suggests an important difficulty in harmonizing the energy mix capable of ensuring a more predictable and manageable structure.

In terms of dynamics, renewables have registered the most important growth (3.33 %, from 38.61 to 110.36 Mtoe), followed by electricity (0.76 %, from 162.24 to 207.29 Mtoe), and natural gas (0.24 %, from 170.79 to 184.67 Mtoe), while solid fuels registered the most significant decline (-5.09 %, from 86.92 to 16.29 Mtoe), followed by other sources (-1.93 %, from 18.22 to 9.74 Mtoe), heat (-0.84 %, from 55.10 to 41.98 Mtoe), and oil (-0.37 %, from 374.56 to 331.79 Mtoe).

Oil remains the main source of the final energy consumption still accounting for 36.78 % (from 41.32 % in 1990) followed by electricity, with an increasing weight from 17.90 % (1990) to 22.98 % (2022), and natural gas, also with an increased weight - 20.47 % (2022) compared to 18.84 % (1990). The treble oil - electricity - natural gas has consolidated its position as the most relevant mix of sources of final energy consumption with a cumulated weight of 80.23 % (2022), slightly higher than in 1990 (78.06 %), while the pair oil - natural gas continue to represent the backbone of the final energy consumption even though its cumulated weight has slightly dropped from 60.16 % (1990) to 57.25 % (2022). Renewables have registered the most spectacular growth in the final energy consumption, from 4.26 % (1990) to 12.23 % (2022), illustrating both the concern for greening the final consumption and the commitment to make it happen. These trends have been accompanied and supported by an even stronger decline in the weight of solid fuel sources, from 9.59 % (1990) to 1.81 % (2022).

The **energy sources** employed represent one of the predictors of the final energy consumption. The analysis of the overall energy production reveals that the total production has decreased at the level of the European Union from 741.70 to 562.85 Mtoe, corresponding to an annual average negative rate of -.85 %, significantly higher compared to the similar value of the final energy consumption.

Analysis of the sources employed to produce energy revealed a strong trend represented by a similar and statistically significant associated evolution registered by natural gas (r=.959, p<.001), solid (r=.882, p<.01), oil (r=.878, p<.01), and nuclear (r=.706, p<.05). A second trend, statistically significant but opposite associated evolution was registered by renewables (r=-.899, p<.001), and a third, rather peripheral, trend with reverse, of average intensity, yet not statistically significant connection was registered by diverse sources (r=-.618). It is remarkable the reverse, very strong, and statistically significant relationships between the renewables and natural gas (r=-.953, p<.001), oil (r=-.937, p<.001), and solid (r=-.936, p<.001), confirming that renewables tended to compensate the classical sources employed to produce energy, a similar evolution (just strong in terms of intensity), being observed for other sources.

In terms of dynamics, renewables have registered the most important growth during the analyzed period (3.93 %, from 70.70 to 243.34 Mtoe), followed by Other (0.89 %, from 13.42 to 17.87 Mtoe). Their positive evolution could not compensate the decreases registered by the rest of the sources: natural gas (-3.86 %, from 123.06 to 34.88 Mtoe), solid (-3.66 %, from 305.50 to 92.50 Mtoe), and oil (-2.37 %, from 40.41 to 18.75

Mtoe) have registered the most pronounced decline, while nuclear has declined less than the overall production (-.60 %, from 188.58 to 155.48 Mtoe).

Two opposite evolutions have illustrated the major shift of the structure of energy production: on the one hand, the strong decline of the solid, from 41.19 (1990) to 16.43 % (2022), and, on the other hand, the strong growth of the renewables, from 9.53 (1990) to 43.23 % (2022). These evolutions have been accompanied by the decreases registered by natural gas, from 16.59 (1990) to 6.54 % (2022), respectively oil, from 5.45 (1990) to 3.43 % (2022). Nuclear energy has increased slightly from 25.43 (1990) to 27.62 % (2022), registering weights higher than 30 percent between 2000 and 2020, with a peak of 33.67 % (2005), while Other sources have also increased their peripheral weight from 1.81 (1990) to 3.17 % (2022).

The evolution of energy production in the European Union between 1990 and 2022 reveals two strategic directions: first, a strong limitation of solid and natural gas as main energy sources, illustrated by the decline of their cumulated weight from 57.78 (1990) to only 22.63 % (2022); second, the strong growth of the renewables – nuclear duo as the backbone of energy production, from 34.96 (1990) to 70.85 % (2022). Renewables have managed to replace Solid as the main source of energy production strengthening once more the intention to green energy production in the European Union expressing both the concern for greening the energy sector and the commitment to make it happen.

It is a fact that the European Union is not able to cover its consumption from its production, which is why the final energy consumption must be backed by imports. The **energy imports** at the EU level have steadily increased in the analyzed period by an annual average rate of 0.76 %, from 1020.42 (1990) to 1300.48 (2022) Mtoe.

Analysis of the energy imports in terms of the structure of the sources revealed a main trend represented by a similar, very strong, and statistically significant associated evolution registered by oil ($r=.927$, $p<.001$) and natural gas ($r=.915$, $p<.001$), respectively a similar, relatively strong, and statistically significant associated evolution of other sources ($r=.691$, $p<.05$). Similar, poor or rather moderate, but not statistically significant associated evolution was registered by renewables ($r=.474$) and solid fuels ($r=.130$). The European Union has imported the necessary energy, mostly oil and natural gas, to cover the market's needs. This behavior will barely change as long as, on the one hand, the main final energy consumers need oil and natural gas to satisfy their needs and, on the other hand, the European Union does not and will not dispose of these types of energy resources.

In terms of import dynamics, renewables have registered a very impressive evolution only in terms of the annual average growth rate of 14.93 %, the quantitative growth being less spectacular – from .25 to 21.48 Mtoe, while natural gas (2.38 %, from 157.78 to 335.74 Mtoe), other sources (1.87 %, from 19.35 to 35.11 Mtoe), and oil (0.34 %, from 732.57 to 819.00 Mtoe, with a remarkable peak of 877.16 Mtoe in 2005) have registered a relatively increasing trend. Solid fuels are the single energy source registering a decline with an annual average rate of -.73 %, from 110.45 to 87.33 Mtoe.

Oil and natural gas have continued to account for almost 90 % of the total European Union energy imports (87.25 in 1990, respectively 88.80 % in 2022) experiencing opposite evolutions in terms of their weight: a decline in the case of oil, from 71.79 to 62.98 %, respectively a growth in that of the natural gas, from 15.46 to 25.82 %. These mutations illustrate the changes in the transportation sector – increased efficiency

of fuel engines, development of electric vehicles, and reconsidering the railways' role. As in the case of consumption and production, solid fuels have diminished the weight in the total of imports, from 10.82 to 6.72 %, while renewables and others have followed the trend expanding their weights: dramatically for the first, from .02 to 1.65 %, naturally for the last, from 1.90 to 2.70 %. Probably one of the most important lessons to be learned is that if there is a need in the market, it must be satisfied even if the internal resources are insufficient.

One of the positive things regarding the evolution of the energy market in the analyzed period was the development of the energy exports that have increased by an annual average rate of 1.38 %, from 275.15 (1990) to 427.75 (2022) Mtoe. Analysis of the **energy exports** in terms of the structure of the energy products reveals that oil ($r=.978$, $p<.001$) and other sources ($r=.906$, $p<.001$) have registered a similar, very strong, and statistically significant evolution. Renewables ($r=.734$, $p<.05$) have also registered a similar, only strong, and statistically significant evolution, while solid fuels ($r=-.849$, $p<.01$) have registered an opposite, very strong, and statistically significant similar evolution. Natural gas ($r=.639$) has registered a similar, relatively strong, but not statistically significant evolution.

Oil and Natural Gas accounted for more than 80 % of the total EU energy exports both registering increases – from 69.72 (1990) to 73.97 % (2022) in the case of oil, respectively from 10.28 (1990) to 11.33 % (2022) in the case of Natural Gas. The export of Solids has followed the same overall evolutions of consumption, production, and imports, decreasing from 14.14 to only 3.08 %, while Other (from 5.81 to 8.24 %) and, particularly Renewables (from .03 to 3.38 %), have increased, quite dramatically in the case of the last, their shares.

As an overall conclusion, during the analyzed period, the final energy consumption has fluctuated around a central tendency of maintaining its level, the increases registered by the transport and commercial and public services compensating industry's decline, with residential also managing to maintain its weight in the total final consumption. Increasing imports have dependently balanced the declining production and exports supplying the market with needed energy. Renewables were the good, solid fuels the bad, while oil and natural gas were the ugly of the European Union's energy market…

One of the attempts – to a certain extent, quite a formal approach, although the creators have had the prudence to specify that "data is used only for comparison purposes and cannot be considered as official data of the EU Reference scenario 2020 or MIX scenario" and that "scenarios are not forecasts – they describe possible future options" – to model the evolutions of the European Union's energy market is the European Commission's EU Reference Scenario 2020 (European Commission, 2020) that analyzes the long-term economic, energy, climate, and transport outlook based on the policy framework in place in 2020 and provides an analytical tool in the areas of energy, transport and climate action in the context of the European Green Deal Package adopted in July 2021 by whose implementation Europe will change dramatically energy production and consumption aiming to become first climate-neutral continent.

The European Commission's Joint Research Centre (JRC) has developed four scenarios regarding the European Union energy: (I) 2030 Reference (the latest Reference Scenario serving as benchmark against new policy proposals); (II) 2030 FF55 Mix

(achieving 55 % greenhouse gas emission reductions in 2030 compared to 1990); (III) 2050 Reference (the updated Reference Scenario providing a benchmark against new policy proposals); (IV) 2050 FF55 Mix (achieving net zero objective in 2050) – and estimated the evolutions of energy use in the European Union and the Member States, by sectors and types of fuels (European Commission JRC Digital Media Hub, 2020). Aggregating scenarios (I) and (III), respectively (II) and (IV), result in two core scenarios: the first under which the specific targets for 2030 and 2050 are reached, and the second under which these particular targets are not reached.

The most interesting observations regarding the data associated with these core scenarios reveal significant changes. First, all three main final energy consumers are expected to register negative dynamics, particularly transport (-1.37 % and -.0.73 % in the first core scenario, -1.80 % and -1.89 % in the second). Residential is next (-.65 % and -.38 % in the first core scenario, -1.50 % and -0.95 % in the second), while industry comes last (-.22 % and, again, -.22 % in the first core scenario, -.85 % and -0.44 % in the second). These changes are expected to rearrange the hierarchy of the final consumers with Industry regaining the first position (at shares varying in the two core scenarios to 23.84 and 24.30, respectively 23.61 and 19.50 %) and Residential maintaining the second place (at shares varying in the two core scenarios to 22.46 and 22.61, respectively 21.75 and 16.19 %). The most severe decline is anticipated for Transport whose market shares will decrease in both core scenarios: 20.81 and 20.03, respectively 21.04 and only 11.75 %.

The spectacular comeback of Industry and the severe decline of Residential and Transport are supported by the changes expected to occur in terms of energy sources by 2030 and mostly in the next two decades with electricity, hydrogen, and e-fuels increasingly replacing oil and natural gas. The Residential is expected to experience radical changes with natural gas and oil diminishing their weight under both core scenarios, from 41 % (2019) to 32 % (2030) and 25 % (2050), respectively to 26 % (2030) and 0 (zero!) in 2050. Electricity and renewables are expected to register opposite evolutions in both core scenarios increasing from 32 % and 16 % (2019) to 35 % and 21 % (2030), and 40 and 23 % (2050), respectively 40 % and 24 % (2030), and 61 and 30 % (2050).

Transport will experience similar evolutions at the expense of oil (natural gas having less significant weight in the sector's energy mix) that will diminish its weight, under both core scenarios, from 93 % (2019) to 86 % (2030) and 74 % (2050), respectively 83 % (2030) and only 10 % (2050). Electricity is expected to register an opposite evolution in both core scenarios increasing from just 1.3 % (2019) to 3.6 % (2030) and 9.2 % (2050), respectively 4.2 % (2030), and 25 % (2050). Hydrogen and e-fuels are expected to enter the scene in the decade 2030-2050, especially under the second core scenario, reaching 0.3 % (2030) and a more than remarkable 36 % (2050).

Finally, Industry is expected to evolve distinctively between core scenarios: under the first, oil and natural gas will maintain their cumulated weight in 2019 – 54 % to similar levels in 2030 – 51 % and 2050 – 53 %, while electricity will slowly increase from 22 % (2019) to 24 % (2030) and 27 % (2050); under the second, oil and natural gas will abruptly decrease from 52 % (2030) to 26 % (2050), while electricity will increase to 26 % (2030) and 37 % (2050), with hydrogen and e-fuels entering spectacularly the scene and reaching an impressive level of 21 % (2050)!

4. Conclusions, limits, and further directions of the research

The European Union's green transition is both a challenge and an opportunity for modern economies under a context described by more jobs, technological progress, social inclusion, new and fast-growing industries, less energy dependency, more competitiveness, empowered consumers, and a crisis-proof climate (European Investment Bank, 2019). As the European Commission stated (2019b), the green transition does not necessarily mean just a simple replacement of conventional with green energy sources, but a challenging transition to be understood and gradually put into practice to shift from fossil fuels towards a carbon-neutral economy.

The results of our exploratory approach revealed several aspects extremely relevant to the content and implementation of the green transition. First, the current positioning of transport as the main final energy consumer, as well as the importance of the specific activities for the movement of people and freight (essential for all goods and services markets) suggests the role of this segment in the transition process. Railways could represent an alternative for the circulation of passengers and goods as their revitalization and modernization (especially by electrifying) have the potential to diminish the weight of oil imports needed to supply road and air transport.

Next, residential and industry segments contribute to the increased vulnerability of the final energy consumers due to their particular needs for oil and natural gas (transport – 94 % oil, industry – 42 % natural gas and oil, households – 41 % natural gas and oil). This import dependency introduces a prevalence of political economics before social and natural dimensions of the macroenvironment with all the consequences in terms of perturbations of the supply chains, procurement costs, and overall market stability. Electricity could represent a solution, particularly if generated from nuclear sources but the current development of this sector is still limited and its perspectives are limited by the security risks associated with the operation of nuclear plants.

The European Union's energy production was not and it is still not capable of covering the needs of the internal market. More than that, the continuous decline of the internal production share in the final energy consumption has generated a constantly higher need for imports and, consequently, an increased dependency on foreign sources, closely associated, as Horúcková has observed (2016) with the concept of energy security that may be under threat to a certain extent by the alignment of the energy sector and the climate goals potentially conflicting with the efforts to increase energy independence.

The growth of renewables share to the total energy production was truly impressive but there is still room for an extended contribution in the coverage of the market needs. The current balance between renewables and the treble natural gas – oil – solid energy sources employed to produce energy for the final consumption suggests that concern for greening is real yet not supported by the available resources. Also, as Macedo and Marques pointed out (2023), the intermittency (due to the natural dependence on weather conditions) and lack of efficient system storage (the attempts to develop this component being extremely recent) make renewables a solution viable on a rather short-term that still must be backed by fossil-based energy sources. On a longer-term horizon, faster penetration and increased use of renewables will contribute to the reduction of the European Union's energy dependency (Streimikiene et al., 2023).

Complementarily, the significant differences between the Member States in terms of the sources employed to produce the energy for the final consumption suggest a real difficulty in harmonizing the strategy and policies implemented in each country and at the Union's level. A such variety of the energy inputs may represent a real impediment in creating a more predictable structure and, consequently, enhances the difficulty to model and manage of the energy mix.

We intended to approach the green transition using a quantitative tool (Markov Chains Analysis) to model the process. The difficulty of establishing the specific transition probabilities, the qualitative aspects to be considered (such as the impact of political decisions over the evolutions of the energy sector), and, last but not least, the simple review of the data regarding the final energy consumption balanced with the energy production, imports, and exports led us to the conclusion that connecting these variables through a mathematical relationship deserves a more in-depth approach. Modeling green transition means, in fact, modeling nature, an attempt rather impossible as, on the one hand, controlling the natural evolutions is extremely complicated (what can be observed in the case of producing renewable energy – there are days when is too cloudy or the wind is not blowing with the appropriate speed), and, on the other hand, the conventional energy reserves have their limits (although, in the most cases, these „limits" tend to refer rather to economical, not to the physical dimension).

Studying the modeling approach initiated by the European Commission (2020) under the framework of the EU Reference Scenario 2020 we have observed at least two debatable aspects that may represent future directions of our research approach: first refers to the dynamics advanced for the final energy consumption, respectively supply, that differs significantly between the reference periods - 1990-2022 and 2019-2050. Thus, in terms of final consumption, the three main segments of the energy sector are expected to register quite opposed evolutions up to 2050 compared to 1990-2022: Transport is expected to decline with an annual average of -.0.73 % in the first core scenario, respectively -1.89 % in the second, compared to the annual average growth rate of 0.74 %; Residential is also expected to decline by -.38 % in the first core scenario, respectively -0.95 % in the second, compared to the annual average rate 0.03 %; finally, Industry will reduce its annual average rate to -.22 % in the first core scenario, respectively -0.44 % in the second, compared to the annual average rate -.98 %.

The second refers to the reasons revealed by the model as potentially supporting these somewhat contradictory evolutions: the decline of oil and natural gas as energy sources employed by the final consumers and their replacement with electricity, hydrogen, and e-fuels, which are expected to reach, by 2050, 61 % of the energy consumed by Transport and Residential sectors, respectively 58 % by Industry. There are solid discussion points regarding on one hand the openness to adopt these technologies and, on the other hand, their efficiency. Connection to the climate-related objectives (reduction of greenhouse gas emissions and reaching net zero objective) adds even more complexity by bringing under debate the political decision-making process and the economic dimension represented by the investments to be made in the field. Fortunately for the designers, the model's disclaimer specifies that data, which is not official, can be used only for comparison purposes and also that scenarios just describe possible future options.

As Mirabeau has observed even in the 18th century (Johnson, 2013), laws that conform to nature are not necessary, and those that contradict it are impossible to put into practice. Placed in the real context of the 21st century, this vision suggests that aligning the evolutions of markets and societies with those of nature represents a better, in fact, sustainable way to support their integrated and organic development. Considering the transition from conventional, fossil-based, to green energy, this inherently organic process should embrace an organic form and have as background the focus on satisfying the needs of an educated, thus responsible energy consumer, by socially responsible providers of energy products and services in a market overseen by also responsible authorities (we have chosen the term "overseen" from a list also including "supervised", "administered", 'managed", and "controlled" considering that expresses adequately the overall behavior of the public entities involved in the energy market). Greening energy consumption and production is good, but not enough or even determinant. Educating consumers to live a sustainable day-to-day life (as close as possible to nature in a favorable economic, social, and cultural context – adaptable/flexible work schedules, with the four-day working week and distance working as top priorities; transport limited to what is useful and convenient for business and/or leisure; producing and distributing good, in the real sense of the word, food and non-food products and services at a fair price-quality of life ratio; supporting and encouraging consumption of cultural/sports products, services, events, and activities) and providing them (by their employers, providers of goods and services, local, national, European or international public entities) with the appropriate environment for all the previously mentioned represents the key reference for living a quality life, also including the organic green transition in the energy market.

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