Review and Perspectives of Key Decarbonization Drivers to 2030

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Abstract

Global climate policy commitments are encouraging the development of EU energy policies aimed at paving the way for cleaner energy systems. This article reviews key decarbonization drivers for Italy considering higher environmental targets from recent European Union climate policies. Energy efficiency, the electrification of final consumption, the development of green fuels, increasing the share of renewable energy sources in the electric system, and carbon capture and storage are reviewed. A 2030 scenario is designed to forecast the role of decarbonization drivers in future energy systems and to compare their implementation with that in the current situation. Energy efficiency measures will reduce final energy consumption by 15.6%, as primary energy consumption will decrease by 19.8%. The electrification of final consumption is expected to increase by 6.08%. The use of green fuels is estimated to triple as innovative fuels may go to market at scale to uphold the ambitious decarbonization targets set in the transportation sector. The growing trajectory of renewable sources in the energy mix is confirmed, as while power generation is projected to increase by 10%, the share of renewables in that generation is expected to increase from 39.08% to 78.16%. Capture and storage technologies are also expected to play an increasingly important role. This article has policy implications and serves as a regulatory reference in the promotion of decarbonization investments.

Keywords:

decarbonization; energy efficiency; CCS; hydrogen; renewable energy; energy policy; green deal; green fuel

1. Introduction

Strategies and paths to decarbonization now represent one of the most thought-provoking topics in the energy and climate literature following the Paris Agreement, which calls on countries to engage in efforts to limit the global temperature rise to 1.5 °C [1]. Provided that an energy transition in power, heat, and transport sectors is feasible worldwide [2], the engagement of all stakeholders involved is needed.

This article reports a forward-looking analysis of the main decarbonization drivers considering recent European Union (EU) climate policies set in the Green Deal, particularly the Fit for 55 package [3], which are instrumental in the EU's goal of reducing net greenhouse gas emissions by at least 55% by 2030. In particular, energy efficiency (EE), the electrification of final consumption, the development of green fuels, the increasing share of renewables in the electric system, and carbon capture and storage (CCS) are considered to be decarbonization drivers.

Recent advances in EU energy policy are prompting the development of new strategies and paving the way for the uptake of innovative energy-system-related technologies. In this sense, a recent article discusses the ongoing changes in European energy policy along with changes that are likely to occur [4]. Indeed, achieving decarbonization in the energy system requires synergies between technological development, policy exertion, and societal attitudes [5].

Provided that such policies can accelerate innovation, promote green growth, and limit polluting activities [6], their successful implementation also depends on expected output and policy fine-tuning in an increasingly complex energy landscape, which scenario analysis can help to clarify [7].

Starting from the EU's scenario on energy, transport, and climate embedded in the Italian National Energy and Climate Plan (NECP), we construct a 2030 scenario that considers the updated economic situation, the pandemic's effect on residential energy consumption and travel demand, and the minimum hydrogen consumption outlined in the NECP. The output in the 2030 scenario was compared with that in 2019, which was set as the reference year.

More specifically, the 2030 scenario focuses on five decarbonization drivers: EE—the potential of which has been significantly exploited over the last twenty years and supported by national legislation, the electrification of final consumption, the development of green fuels, the increasing share of renewable energy sources (RES) in the electric system, and CCS. The first lever for decarbonization is EE, so the primary and final energy consumption and contribution of different sectors to achieving energy savings targets are reported.

Next, we analyze the level of final consumption electrification, which, through increased generation from renewable sources, contributes to the decarbonization of the energy end-use sectors. Then, the role of green fuels is shown to have become particularly significant, and a specific focus is placed on transportation. After that, we focus on the penetration of renewables in the electricity sector and discuss the role of CCS technologies.

We conduct an in-depth study that focuses on Italy, which can be used as a starting point for similar studies, particularly in the context of other EU member states. We keep in mind, however, that the role of the analyzed drivers varies—even remarkably in some cases—according to the structure of economic and energy systems, strategies, and policies across countries.

Achieving the decarbonization goals requires a significant commitment in terms of incremental investments compared to the current trend in energy and generation system development. It must be considered that even without additional policy measures beyond those that already exist and without specifying a decarbonization target, the energy system will incur unavoidable investment costs to be able to perform its normal function due to current technologies and plants reaching the end of their life cycle and needing to be replaced.

Section two presents the decarbonization levels under analysis and provides forecasts to 2030 by comparing them to the reference year. Section three discusses some prominent implications and introduces policy challenges, while section four concludes the paper.

2. Background, Materials and Methods

Scenario analyses can be used to address long-term uncertainty-characterized questions as they are useful in exploring various alternative future pathways [8]. In energy policy, such exercises are often used to support policymakers in designing effective policies [9] and to estimate whether foreseen technological developments are capable of reducing CO2 emissions by a specific date [10].

In light of contingent environmental targets [11] and political commitments [12], decarbonization scenarios must comprehend challenging new dimensions in addition to traditional factors such as technological progress and socioeconomic, demographic, and institutional political considerations. In particular, modern energy forecasts must take into consideration the scope, timeline, and urgency of policies to mitigate greenhouse gas emissions [13].

Scenario analysis makes it possible to identify the main actions, objectives, and sectors with the greatest potential for decarbonization interventions and to provide indications of their infrastructural and technological needs. Furthermore, it allows political decision makers to orient themselves owing to their quantitative assessment of the impacts of energy–environmental objectives and policies and whether there are any overlaps that can be eliminated.

The role and perspectives of key decarbonization drivers can be appraised by starting from the NECP, which incorporated the European Scenario on energy development and the TIMES model elaborated by the RSE, which is the Italian Research on Energy System company. To take recent policy events into consideration, such as EU climate policies related to the Green Deal, we constructed a scenario for 2030 that considers the updated economic situation, the pandemic's effect on residential sector energy consumption and travel demand, and the minimum hydrogen consumption outlined in the NECP.

Starting from the scenario reported in the national environment climate plan (NECP), additional factors such as a modification of emissions during the pandemic, additional requirements from the Fit for 55 package, and recent public spending programs, were considered. Although the EU commission published some impact assessments, the package implications for EU countries vary according to industrial activities, economic factors, and energy efficiency levels, to mention a few.

The output in the 2030 scenario was compared with that in 2019, which was set as the reference year. The 2030 scenario is built on the basis of existing information regarding technologies, technical constraints to industrial processes, and development programs and places, showing that there was no limit on the potential for further development in relation to technological improvements and increased economic efficiency, as well as new policy directions (such as the recent proposals contained in the REPowerEU package).

In Italy, for example, the proposed revision of the EE Directive [14] has helped to define a national target for the final energy consumption of approximately 94 Mtoe in 2030, compared to 115.4 Mtoe in the base year. In that scenario, 97.1 Mtoe is achieved through multiple levers, depending on the available decarbonization options. For example, the promotion of green fuels and the presence of CCS allow for the mitigation of EE leverages under the same decarbonization targets.

3. Resume of Decarbonization Drivers

3.1. Energy Efficiency

EE is a central target for energy policy and a keystone for mitigating climate change and achieving sustainable development [15]. EE is one of the pillars of energy policy, provided that it contributes to achieving emissions reduction targets [16], ensuring greater supply security through reduced energy demand [17], and promoting the transition to a sustainable energy system [18]. In Europe, the Green Deal has set ambitious environmental targets to 2030 to reach net-zero emissions by 2050 [3]; as a consequence, existing legislation is being updated to accommodate that transition [19].

The breakdown of sectoral contributions is a product of the approach used in our estimates. To minimize system costs, sectors with the greatest potential for efficiency gains and interventions and an attractive cost-effectiveness ratio are identified to ensure that the efficiency directive target is met and to promote a further reduction in emissions in the furtherance of European decarbonization programs. Figure 1 shows the sectoral details of forecast savings to be achieved by 2030.

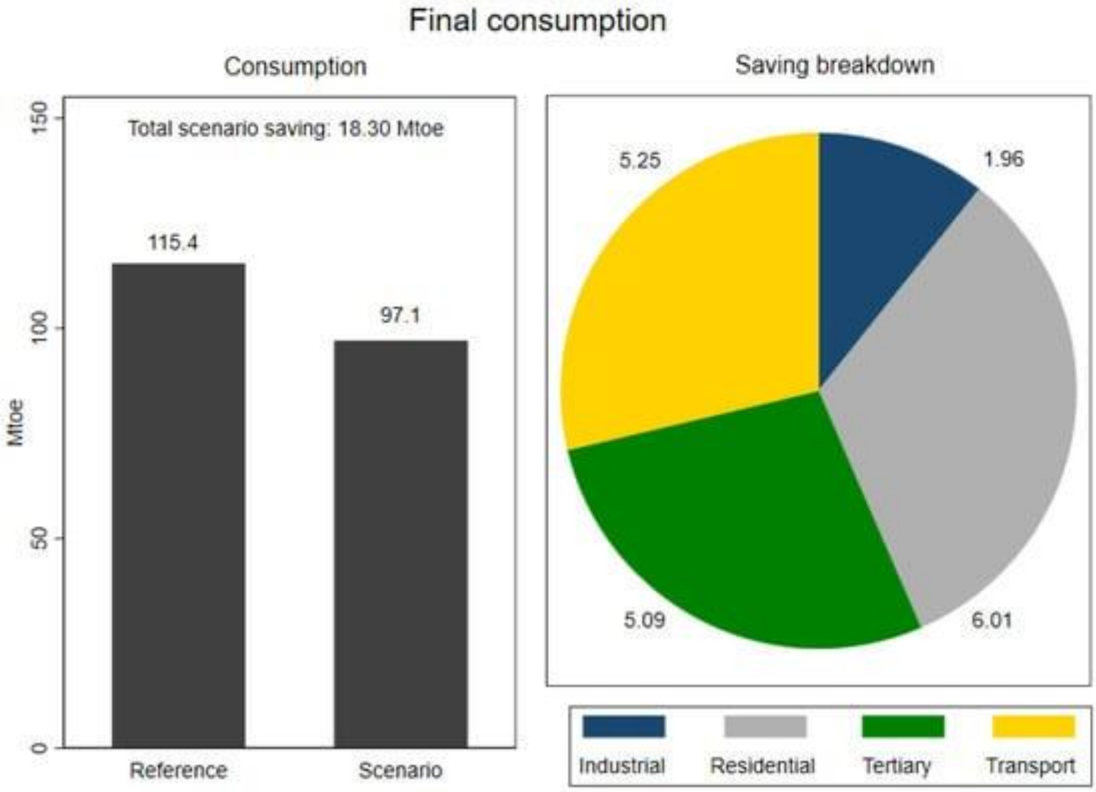

Figure 1. Consumption and final consumption savings by 2030. Note that reference stands for 2019 data.

The civilian, residential, and tertiary sectors emerge as the main sectors for implementing efficiency measures, which is consistent with previous insights [20]. As expected, the industrial sector achieves a consumption reduction of approximately 1.96 Mtoe, given that this sector has already reduced its emissions to a large extent, particularly since the implementation of market-based mechanisms aimed at supporting EE [21]. That said, the industrial sector should be analyzed differently from the others; it is, in fact, a sector in which CCS technologies complement other solutions, particularly in the so-called hard-to-abate sectors [22,23]. Another major contribution to efficiency comes from the transportation sector [24]; thus, our hypothesis is based on the gradual increase in green fuels, such as biogas, biomethane, biodiesel, bioLPG, rDME, etc., as well as electrification consistent with the limited growth in electricity consumption. The main increase in renewable consumption (1.1 Mtoe) is in the transportation sector due to the introduction of biofuels. In contrast, the main source of growth for petroleum products is in the agriculture sector, with an increase of 0.3 Mtoe, followed by the civil and industrial sectors (+0.1 Mtoe in both). Figure 2 shows the final energy consumption by sector and source, highlighting the following decreases in all sectors when taking into consideration the source analysis: petroleum products—37%, natural gag—27%, renewables—65%, electricity—5%, derived heat—2%, and solid fuels—28%.

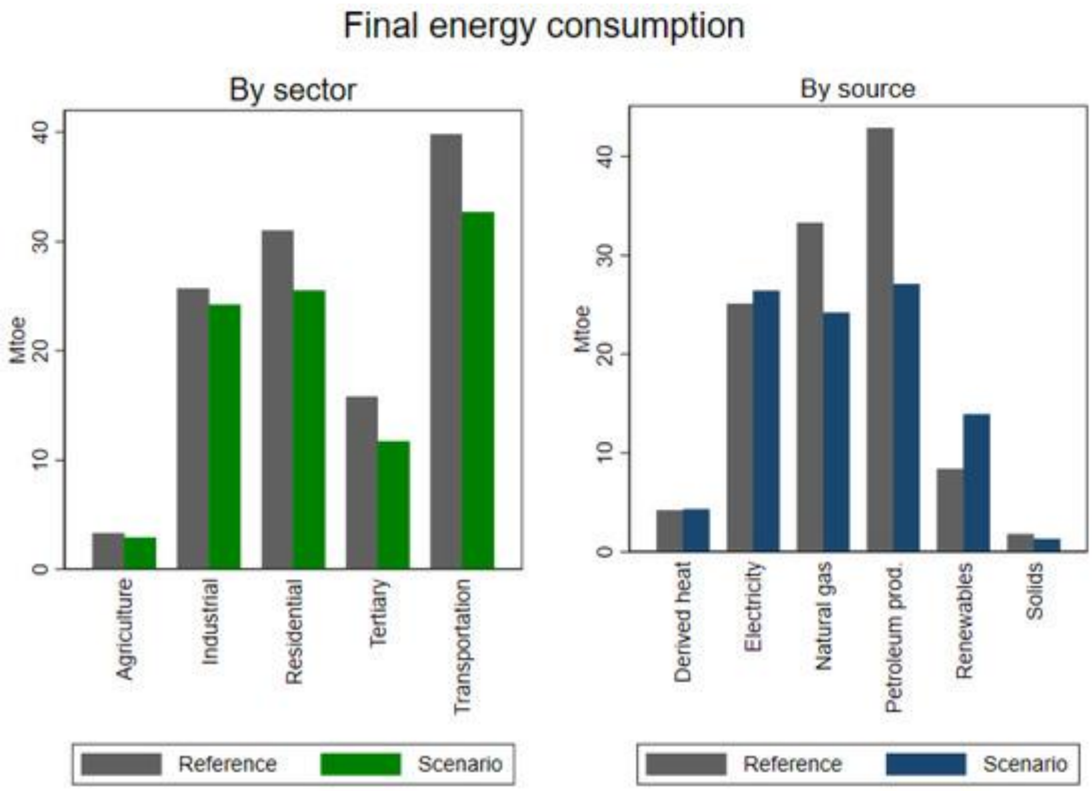

Figure 2. Final energy consumption by source. Note that the scenario refers to a 19% reduction, as shown in **Figure 1**.

Primary energy consumption must also be analyzed. The evolution of new emissions targets for 2030 tends to amplify the use of EE technologies and tools while reducing primary energy requirements. As shown in Table 1, compared with the base year, the 2030 scenario foresees approximately 30 Mtoe less primary demand, which is consistent with the increasing decoupling between gross domestic primary energy consumption and gross domestic product [25,26], even if one should consider that absolute decoupling is not possible between total final energy consumption and GDP in the short period. Interestingly, a recent study analyzed decarbonization drivers and found that the penetration of renewables and decreases in energy use imply decreasing emissions even if the decrease in energy use was also explained by a lower growth in gross domestic product [27].

Table 1. Primary energy consumption (Mtoe).

	Reference	2030 Scenario
Petroleum products	54	35
Natural gas	60.9	40.9
Renewables	27	42.3
Electricity import	3.3	2.5
Solid fuels included coal	7.7	1.8

Table 1 shows the change in primary consumption in the 2030 scenario compared to the baseline year.

3.2. Electrification of Final Consumption

As discussed previously, the 2030 scenario shows higher electricity consumption than base-year levels, which is indicative of increased electrification in all end sectors, as shown in recent studies, e.g., on residential [28,29], industrial [30], building [31], and transport sectors [32]. To this extent, potential grid reliability problems in light of the penetration of renewables may arise [33]. On average, the electrification of end-use consumption increases by 6% by 2030. Figure 3 shows the evolution of electricity consumption in end-use sectors in the 2030 scenario and a comparison with the reference year. The increasing demand for electrical services (e.g., heat pumps, air conditioning, and cooking uses) is offset by improvements in the average EE performance of appliances and boosted by minimum energy performance standards and energy labels [34], provided that such products are designed for efficiency [35], as well as the development of EE product markets [36]. Interestingly, it is estimated that the electrification of agriculture is also set to increase, primarily due to the electrification of agricultural vehicles and the EE improvement of agricultural facilities; in the tertiary sector and the residential sector, prominent drivers are building redevelopment, electrical equipment and lighting, heating, and heat pumps.

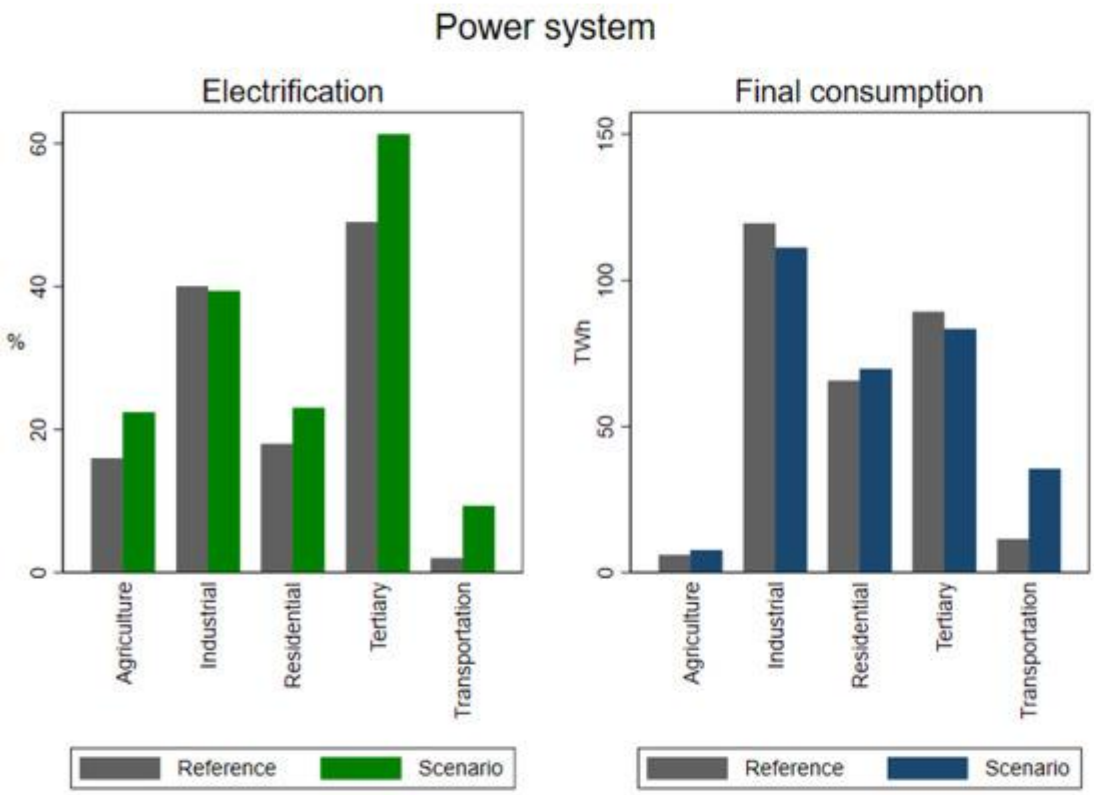

Figure 3. Final energy consumption and electrification.

The electricity demand curve in the end-use sectors does not see significant growth in the immediate future even if electrification continues in the coming decades. Considering the level of electrification of sectors, there are positive changes in electricity consumption in the tertiary and transportation sectors, as shown in Figure 3. The most noticeable development is in the transportation sector, which increases from 2% to 9.3% due to the spread of electric vehicles, given the increasing role of renewable power generation [37] and the dependence on market penetration and business models [38,39]. In the industrial sector, the level of electrification remains stable, provided that new technologies and measures taken to balance fluctuations in renewable production, such as electricity storage, energy demand adaptation, and sector coupling, impact the pace of decarbonization [40]. What emerges from the analysis of EE is that is it still a prominent driver for decarbonization and that there are improvement perspectives in the tertiary and transportation sectors, whereas the EE of the industrial sector has improved a great deal over the last fifteen years thanks to the white certificate program.

3.3. Green Fuels

The production of alternative fuels is expected to play a key role in decarbonization [41]. The 2030 scenario foresees the use of renewable sources for thermal and transportation purposes along with the penetration of green fuels produced from biomass sources through different biological and thermochemical processes [42]. This results in more renewable sources in end-use energy consumption compared with the baseline year, as Table 2 shows.

Table 2. The final consumption of green fuels in transportation (Mtoe).

	Reference	2030 Scenario
Biomethane		0.9
Renewable dimethyl ether		0.3
Hydrogen		0.3
e-fuels		0.2
Bio-LPG		0.4
Biofuels	1.3	1.7

For example, biomethane reaches 2.9 Mtoe of final consumption, of which 0.4 Mtoe is used for electricity production. Approximately 0.9 Mtoe of biomethane is employed in the transport sector, as shown in Table 2, which is favored by the feed-in obligations and targets of Directive 2009/28/EC, as well as by the incentive for its use in the transport sector. The use of biomethane is driven by the increase in emission targets and new prospects for reducing the investment costs of electrolyzers used in the production of green hydrogen, which, together with CO2 from biogenic sources, can be transformed into carbon-free methane along with other fuels such as HVO diesel [43], biojet [44], bio-LPG [45], and renewable dimethyl ether [46]. In the 2030 scenario, approximately 64% is used in the transport sector, and the remainder is used in the civilian sector.

Hydrogen is one of the main distinguishing features of the 2030 scenario, in which there is approximately 0.52 Mtoe of green hydrogen consumption for both energy and nonenergy uses. The industrial and transportation sectors will use hydrogen among their main sources of energy consumption. In contrast, the refinery and petrochemical sectors will begin to replace gray hydrogen produced from fossil fuels without capturing emissions with green hydrogen. Table 3 shows the consumption of green hydrogen in different sectors and by type. However, it should be taken into consideration that green hydrogen and its compounds are likely to be utilized as alternative fuels in the future for air and sea transportation, large trucks used for long-distance freight, and steel and aluminum. However, it seems unlikely that they will be cheap enough to play a significant role by 2030.

Table 3. Green hydrogen consumption by sector.

Sector	2030 Scenario (Mtoe)
Industry	0.15
Transportation	0.29
Refinery	0.06
Petrochemical	0.02

To conclude this section, it is worth noting that the role of green fuels is still ambiguous although the proposal contained in the Fit for 55 package may boost the uptake of green fuel, especially in the heavy vehicles.

3.4. Renewable Sources in the Electricity System

Another important decarbonization lever is the deployment of renewable energy sources (RESs) in the electricity system. The growth of RESs helps to decarbonize end-use sectors and thus accompanies the transition to a low-emissions economy provided that intermittent RESs increase the demand for flexibility in the electric system [47]. With reference to electricity demand, in the 2030 scenario, the electricity demand is 346 TWh, as shown in Table 4. The final electricity consumption and dedication to hydrogen production processes from electrolysis increase, although to a limited extent in refineries; in fact, a technological option that allows classic petroleum products to be produced from biological sources has been introduced in the 2030 scenario. Thus, there is more domestic production and less reliance on biofuel imports in the 2030 scenario.

Table 4. Network electric demand (TWh).

	Reference	2030 Scenario
Final electrical consumption	291.9	307
Refineries and other uses	9.9	10
Power-to-X		8.1
Network losses	17.8	20.9
Total	319.6	346

Table 5 contains some relevant items of information regarding electricity supply. The role of renewable energy sources increases considerably; energy produced from renewable sources by 2030 will reach 227 TWh, representing more than 70% of the electricity generation mix.

Table 5. Mix of total electric energy generation (TWh).

	Reference	2030 Scenario
Coal	21.3	
Gas	144.8	92.3
Petroleum products	10.2	3.6
RES	115.8	227
Other	4.2	3.1
Total	296.3	326

In terms of installed capacity, the 2030 scenario shows a need for an additional renewable capacity of approximately 61 GW, mainly from photovoltaics and wind. With this, existing plants that reach the end of their life cycle must be replaced, which brings the investment in new renewable capacity to be installed by 2030 to more than 72 GW. It is worth mentioning that the Italian green transition plan has projected that to reach a renewable energy share of approximately 72% of the electricity generation mix, the installation of approximately 70–75 GW of new renewable capacity is needed. Finally, the elaborations in this study were carried out prior to the REpowerEU package, showing that additional capacity is likely to be needed in order to comply with the 2030 targets as well as the subject of ongoing national discussions. What emerges from the analysis of the penetration of renewables in the electric system is that a clear path exists and that, consistently with IEA forecasts, renewables are expected to replace a remarkable share of natural gas and coal.

3.5. Carbon Capture and Storage

The 2030 scenario includes the possibility of using CCS technologies (as shown in Table 6) in the industrial sectors and power generation, and a minor contribution in the refining sector with the use of blue hydrogen is also considered. Put differently, CCS, in terms of its use in hard-to-abate industrial sectors, is mainly concentrated in the cement and steel sector. Then, to support renewables and ensure grid balancing, CCS is applied to 1 GW of natural gas in a combined cycle power generation. Finally, to produce green hydrogen, CCS is used by capturing approximately 0.2 million tons of CO_2 in 2030.

Table 6. CO_2 captured by CCS technologies (million tons).

	2030 Scenario
Power generation	2
Industry	2.1
Refineries	0.2
Total	4.3

It should be taken into consideration that the total emissions captured by CCS technologies may represent approximately up to 0.13% of the total emissions considered in this paper. Further developments that different technologies might have in relation to technological improvements and increased cost-efficiency or new directions in terms of policy objectives, such as the Commission's recent proposals in the REPowerEU package, may change even in a relatively short period, including the estimates derived from the 2030 scenario analysis provided in this article. In fact, the EU considers renewable hydrogen a key priority for achieving climate neutrality and therefore intends to develop the hydrogen industry [48]. In this respect, a recent study has investigated the challenges and opportunities of green and blue hydrogen production which are deemed to be foundational to a potential hydrogen society [49]. With regard to CCS, remarkable investments are planned by industry, particularly within industries in which emissions are hard to abate. Firms are increasingly committed to reducing Scope 1 and Scope 2 emissions, and Scope 2 emissions are being frequently compensated using carbon offset markets and buying guarantees of origin energy. Instead, CCS technologies are a direct way of coping with Scope 1 emissions and representing direct investments in plants. It should be taken into consideration, however, that CCS and biofuels are likely to make only a small but significant, also in terms of technological innovation, contribution to emissions reduction by 20230 whereas remarkable improvements are expected by 2050.

4. Discussion

The decarbonization process is characterized by multiple factors and uncertainties that make it difficult to identify a single evolutionary path. Scenario analysis makes it possible to explore multiple possible paths that help to achieve decarbonization goals by analyzing alternative hypotheses. This approach makes it possible to identify the main actions, objectives, and sectors with the greatest potential for decarbonization interventions and to provide indications of their infrastructural and technological needs.

In light of changing climate policies, decarbonization scenarios must comprehend challenging new dimensions in addition to traditional factors such as technological progress and socioeconomic, demographic, and institutional–political considerations; So, the need to rethink green growth policies and complement efficiency is increasingly urgent [50].

This article provides insights into the potential role of key decarbonization drivers and focuses on Italy by 2030. Consequently, the role of each lever changes from country to country and even at the local level, given the importance of local factors [51]. For example, the role of EE in Italy being set to change slightly in the next decade does not mean that this forecast is applicable to other countries. More specifically, this is because over the last twenty years, remarkable EE gains have been made by Italian industries and supported by the white certificate mechanism [21,52]. In this regard, EU countries have followed peculiar strategies within their respective EE obligation schemes [53,54].

In addition, due to the increasing number of policy and regulatory tools aimed at supporting decarbonization, a prominent challenge is the coexistence and combination of alternative tools that, if properly designed, may accelerate that path. Indeed, interactions between policy instruments may lead to substantial added value compared to their stand-alone implementation [55]. However, there are circumstances in which the coexistence of alternative policy tools may bring about unexpected outputs in terms of cost efficiency [56,57].

Combining energy and economic forecasts is challenging. Based on the estimates of our scenario analysis, it is also possible to make a preliminary estimate of the investments needed to meet climate goals. The cost attributable to decarbonization is the additional cost for more expensive investments or interventions that are not included in the trend forecast. Given the approximately EUR 1120 bln investment required to fulfill the Fit for 55 targets, it is estimated that approximately EUR 147 bln of additional investment is needed over the 2020–2030 period compared to previous forecasts.

Based on recent estimates, further analysis is needed to estimate the effects of investment on public finance so that their cost-effectiveness can be assessed in both environmental and economic terms. Future research should therefore also focus on the opportunities and risks arising from the coexistence of multiple environmental policies that, although they may have the same objectives if not managed appropriately, could generate rebound effects that reduce their effectiveness. In addition, new regulatory tools should be considered to support policymakers in designing effective climate policies [58].

5. Conclusions

Decarbonization has become one of the most thought-provoking topics in energy and climate policy. This article reports a forward-looking analysis of the main decarbonization drivers considering recent EU climate policies set in the Green Deal, particularly the Fit for 55 package, which are instrumental to the EU’s goal of reducing net greenhouse gas emissions by at least 55% by 2030.

This paper is based on a 2030 scenario analysis in which output is compared with that of the reference year, which is set to 2019. The 2030 scenario focuses on five decarbonization drivers: EE, the electrification of final consumption, the development of green fuels, the increasing share of renewables in the electric system, and CCS.

This analysis focuses on Italy, which can be used as a starting point for similar studies, particularly in other EU member states. We keep in mind, however, that the role of the analyzed drivers varies according to the structure of economic and energy systems, strategies, and policies across countries.

EE is a central target for energy policy and a keystone for mitigating climate change and achieving sustainable development. The final energy consumption changes from 115.4 Mtoe in the reference year to 97.1 Mtoe in the 2030 scenario, which corresponds to a 15.6% reduction that is achievable through multiple levers depending on the available decarbonization options. Similarly, primary energy consumption drops from 152.9 to 122.5 Mtoe, which corresponds to a 19% reduction.

The electrification of end-use consumption increases from 25% to 31.02% in the 2030 scenario. The increasing demand for electrical services (e.g., heat pumps, air conditioning, and cooking uses) is offset by improvements in the average EE performance of appliances and boosted by minimum energy performance standards and energy labels, provided that such products are designed for efficiency and the development of EE product markets.

The 2030 scenario foresees the use of renewable sources for thermal and transportation purposes along with the penetration of green fuels that are produced from biomass sources through different biological and thermochemical processes. Hydrogen is one of the main distinguishing features of the 2030 scenario, in which there may be approximately 0.52 Mtoe of green hydrogen consumption for both energy and nonenergy uses. The industrial and transportation sectors will use hydrogen among their primary sources of energy consumption. In contrast, the refinery and petrochemical sectors will begin to replace gray hydrogen produced from fossil fuel without the capture of emissions with green hydrogen.

In the 2030 scenario, the electricity demand in 2030 is 346 TWh. The role of renewable energy sources increases considerably, and energy produced from renewable sources will reach more than 70% of the electricity generation mix by 2030. In terms of installed capacity, the 2030 scenario shows a need for an additional renewable capacity of approximately 61 GW, mainly from photovoltaic and wind power. The 2030 scenario includes the possibility of using CCS technologies mainly in the cement and steel sector, although it is limited to 4.3 million tons of CO_2 captured in 2030.

Based on the estimates of our scenario analysis, it is also possible to make a preliminary estimate of the investment needed to meet climate goals. Assuming that approximately EUR 1120 bln investment is required to fulfill the Fit for 55 targets, it is estimated that approximately EUR 147 bln of additional investment is needed over the 2020–2030 period compared to previous forecasts.

The added value of this analysis is that it clarifies the potential impact of decarbonization drivers in different economic sectors to support policymakers in developing environmental policies that are complementary to those of supranational bodies and target the specific needs of individual sectors.

The results help to identify the main actions, objectives, and sectors with the greatest potential for decarbonization interventions, and also provide indications of their infrastructural and technological needs. This paper also helps policymakers orient themselves owing to its quantitative assessment of the impacts of energy–environmental objectives and policies while eliminating any overlap.

Future research should focus (i) on cross-country comparisons and sensitivity analyses to identify structural investment needs to assist the transition to a low-emissions economy at the lowest cost; (ii) on the perspectives of each of the decarbonization drivers, (iii) on cost opportunity of investments; and (iv) on the coexistence, overlapping, or counterbalancing of public policies.

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