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Meeting decarbonization targets: Techno-economic insights from the Italian scenario

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Abstract

The European plan for a green transition includes the Fit for 55 package, designed to pave the way for climate neutrality. Despite its significant implications for cleaner technologies, it potentially correlates with high investment requirements, necessitating the pursuit of cost-effective environmental policies. Starting from the reference scenario previously envisaged in the Energy and Climate Plan, socioeconomic and environmental impacts are assessed using mixed methods. It is estimated that €1120 bn in investments are needed to meet decarbonization targets, while the total impact on public finance revenues to 2030 is projected at €529 bn. Additionally, the avoided costs of emissions amount to €36 bn, while those from energy savings are expected to reach €30 bn. This paper adds value by contributing to the literature on European climate policies, offering an in-depth appraisal of implications that integrates technoeconomic and environmental perspectives. Furthermore, it informs policymakers' public spending decisions for decarbonization.

1. Introduction

Climate change presents an existential threat to the world, and counteracting it necessitates political commitment from all states to promote high-level climate initiatives. The European Commission (EC) has adopted the Green Deal, a new growth strategy aiming to transform the European Union (EU) into a prosperous society with a competitive, resource-efficient economy that is decarbonized by 2050. This strategy ultimately seeks to uncouple economic growth from resource use [1]. The EU Green Deal incorporates a series of proposals to reduce emissions by 55% by 2030 compared to 1990 levels, in addition to binding the goal of climate neutrality to 2050.

The Fit for 55 package is designed to prepare the way for EU climate neutrality in 2050 [2] and has important implications for EU environmental and climate policies. The most important proposals include updating and expanding the emission trading system, increasing targets on energy efficiency and renewable energy use, increasing penetration of low-impact transport vehicles, taking measures to prevent carbon leakage, making changes in taxation and fiscal policies, and taking actions to preserve and increase natural carbon stores such as forests and other ecosystems. It comes with potentially significant investment requirements and costs that urge pursuing the most cost-effective policies. A recent study found that several aspects could further improve the cost-effectiveness of current EU climate policies [3]. Among the changes proposed through Fit for 55, it is worth highlighting the following.

First, the Energy Efficiency Directive has been recast, from which national energy efficiency targets have been established [4,5]. The Directives of the European Parliament and the Council 2018/2002 and COM/2021/558 require Member States to almost double their annual energy savings [6].

Second, Directive 2018/2001 on promoting energy use from renewable sources was revised according to the EC proposal COM/2021/557. The revision sets a new target of 40% renewable energy sources (RES) in final energy consumption by 2030. This target requires doubling the penetration of RES in the European energy mix by 2030 [7].

Third, provided that the Effort Sharing Regulation 2018/842 consists of individual binding emission reduction targets for EU countries, which are given various options to achieve compliance in a supposedly flexible and cost-effective way [8], the Fit for 55 calls for increased emission reduction targets from −30% to −40% compared to 2005 by 2030.

Provided that climate policy instruments can be divided into command and control and policies based on market mechanisms [9], a policy impact analysis topic gaining momentum among scholars and policymakers is the coexistence of different policy tools heading toward similar goals. Within climate change policy options, policymakers increasingly combine multiple tools to achieve decarbonization targets [10]. Previous literature has noted that the combination of policy instruments that are part of EU climate policy can have significantly different effects in different European countries [11,12].

Despite convergence in goals, this may result in overlapping, complementary, or eventually counterproductive outcomes [13]. In contrast, a recent study demonstrated that policies could diffuse as a result of an interdependent process of states learning from and emulating each other, coordinated by international organizations [14]. For example, another study suggested that the consequences of climate policy interactions can be costly in particular market conditions, making the interaction of carbon pricing policies and renewable targets hazardous [15]. Because global convergence on climate policy goals has become urgent, overlaps in climate policies characterized by institutional diversity may threaten the decarbonization path [16]. It is no wonder that there is a need for specific analyses to support the scientific community, regulators, and policymakers in understanding the implications of climate policies.

Starting from the reference scenario (RSNECP), which is the scenario foreseen in the Italian Integrated Energy and Climate Plan 2030, updated according to the latest available statistical data and events affecting the energy system, we assessed the economic impact of the Fit for 55 package through a policy scenario (PSFF55). The PSFF55 includes recent economic updates, the pandemic effect on energy consumption, the hydrogen consumption predicted in the preliminary guidelines of the Italian hydrogen strategy, and the energy measures of the 2021 National Recovery and Resilience Plan.

The research questions (RQs) were straightforward. RQ1 aims to understand in what sectors and the amount of investments required to comply with the Green Deal decarbonization targets boosted by the Fit for 55, RQ2 focuses on the socioeconomic consequences of meeting such targets, and RQ3 is about environmental issues in terms of avoided emissions due to investments in decarbonization.

To answer these questions, the research strategy was based on mixed methods research following the triangulation principle to enhance the validity of the findings and mitigate the presence of any research biases that typically emerge in scenario analyses.

Reliable information specific to investment strategies and prominent technologies was sourced from a focus group of experts from the national business association. This source enabled the quantification of investment gaps. Meanwhile, to estimate the socioeconomic implications, we relied on the well-known economic analysis tool known as input–output analysis (IOA). This is a viable approach for analyzing the sectoral interdependencies that characterize the system, represented by the flows of goods and services within a general economic equilibrium context. The analyses were conducted using the Italian national symmetric input–output tables for 63 economic sectors.

The remainder of the document is organized as follows: Section Two provides the background information, outlines the analytical approach used for the analyses, and defines the scenarios. Section Three presents the results, highlighting the effects on the economic system, the implications for public finance, and the positive externalities resulting from reduced emissions and energy savings. These results are then discussed in Section Four, which is followed by the conclusion.

2. Background

The decarbonization of economic systems is one of the most debated topics in the literature today, particularly after the global commitment to limit the global temperature rise to 1.5 °C [17].

With the aim of contextualizing the expected investments in technologies for the green transition, this section reviews the main drivers of decarbonization in light of recent European climate policies established in the Green Deal, including the fit for 55 package that aims to reduce net GHG emissions by at least 55% by 2030 and set ambitious decarbonization targets to be achieved by 2050 [1]. Existing policies and legislation are being updated to accommodate this transition [18], along with the design of efficient carbon markets that concurred in gradually reducing carbon emissions while preserving fair competition [19]. Indeed, finding an equilibrium between environmental and economic sustainability is challenging.

Based on data provided by the Italian business association in the scenarios and economic impact assessments of the fit for 55 objectives 2022 report [20], the economic analysis in this paper presumes that overall investments will heavily occur in five areas that represent the drivers of decarbonization: energy efficiency, electrification of end-use consumption, green fuels, renewable energy, and carbon capture and storage.

Energy efficiency is key to mitigating climate change and achieving sustainable development [21]. It is not surprising that it is one of the pillars of energy policy [7], helping to ensure greater energy security by reducing energy demand and reducing external dependence [22] and promoting the transition to a sustainable energy system through the more rational use of energy. The civil, residential, and tertiary sectors are the main sectors for implementing energy efficiency measures. Similarly, the transportation sector is also expected to achieve significant results [23] as the industrial sector [24,25]. Increased electrification is also expected, for example, in the residential [26,27], industrial [28], construction [29], and transportation [30] sectors.

Nevertheless, the increase in demand for electrical services is offset by improvements in average energy efficiency performance and stimulated by minimum energy performance standards [31], provided such products are designed for efficiency as well as by the development of markets for energy efficiency products [32]. The most obvious development is in the transportation sector, which is also given new business models. In the industrial sector, electrification will also increase due to technologies [33] supporting the new electricity market characterized by increasingly differentiated energy production.

Additionally, green fuels are likely to play a key role in decarbonization despite recent advancements in electrification [34,35].

Another important decarbonization lever is deploying renewable energy sources in the electricity system. There are well-known relationships between economic development and greenhouse gas emissions where renewable energies concur to smooth such a relation [36]. As is well known, the growth of renewables helps boost the transition to a low-emission economy [37]. That said, the process of phasing out from fossil fuels in a cost-effective manner is not linear and involves considerably different efforts by European countries [38]. Industrial sectors are predicted to adopt carbon capture and storage technologies, with a substantial usage of these technologies in power generation expected to significantly aid in decarbonizing the industry [39]. The EU views renewable hydrogen as a crucial element for attaining carbon neutrality and plans to foster growth in the hydrogen sector [40]. In this regard, a recent study analyzed the challenges and opportunities of green and blue hydrogen production, which are crucial for a potential hydrogen society [41]. Given the diversity of these domains, decarbonizing the economy requires synergies between technological development, political commitment, societal attitudes, and investment strategies [42].

Similarly, given that multiple factors and uncertainties characterize the decarbonization process, scenario analyses are useful for asking questions characterized by medium- and long-term uncertainty [43].

In climate policy, scenarios are often used to support policymakers in designing effective policies [44] and to estimate whether planned technological developments are suitable for reducing CO2 emissions by a level consistent with the goals set [45].

Previous literature evaluated the economic implications of alternative energy policies for Europe's power sector [46], and forecasts show that ambitious emission reduction targets can be obtained cost-effectively if transmission and storage capacities are expanded adequately [47], considering that emission reductions in the energy supply sector are dominant up to 2030 [48]. While previous studies have delved into alternative scenarios regarding decarbonization, this paper contributes to the existing body of knowledge in more dimensions. First, we provide information on anticipated investments in key technologies for decarbonization. Such insights are instrumental in examining the potential evolution of strategic industries. Second, we investigate the possible effects of recent climate policies and crises, as mentioned in the methodological section, on the Italian economy, which offers a template for potential replication in other nations. Third, helping in understanding how costs and goals outlined in the NECP might shift to align with supplementary requirements. This serves as a valuable resource for recalibrating current policies.

In this regard, the approach used in this paper allows for a detailed analysis of the potential impact of climate policies on the economy by focusing on the decarbonization drivers identified in this article. In particular, the paper provides concrete figures such as estimated investment needs, potential returns and avoided costs, making the results more actionable for stakeholders. Finally, by highlighting areas that require further investigation, such as the impact of the REPowerEU plan and potential setbacks resulting from the implementation of high-level policies, the paper lays the groundwork for future research.

Nevertheless, it is worth noting that this paper has limitations; for example, the choice of decarbonization drivers could vary based on different perspectives, countries or methodologies. Additionally, the expected investments are heavily predicated upon local legislation and incentives, which might not be universally applicable. In addition, the significance of individual sectors to the economy could undergo shifts, altering the impact of these findings. Despite these challenges, the research method aligns with the primary aims of this paper.

3. Research method

Given the ambitious nature of the Fit for 55 targets, which will necessitate extraordinary investments, we can reasonably expect the impact of such investments to be felt across a wide range of sectors. To model the extent and manner in which these investments may affect the economy, we have chosen the input–output analysis (IOA) approach, which provides a valuable framework for analyzing policy impacts [49] and assessing the impacts of exogenous demand variations on prominent economic variables such as output, value added (VA), intermediate inputs, primary inputs, and employment. Once the demand variation is distributed among the sectors, IOA facilitates the calculation of the production required to meet the demand in each sector [50]. The demand was estimated based on data provided by documents and experts from the Italian business association; this estimated amount was then used as input for the IOA. The analysis is based on symmetric input–output tables featuring 63 economic sectors as classified according to NACE Rev. 2 (Statistical classification of economic activities in the European Community), as demonstrated in Annex 1 that resumes the structure and data of the Italian 63 sectors input–output symmetric table.

Symmetric input–output tables depict the production processes and transactions within an economy, illustrating how the output of one sector becomes input for another, as exemplified in the pioneering models of this kind [51].

Table 1 presents a simplified input–output matrix. For ease of presentation, various elements of net final demand, which include the final consumption expenditures and gross capital formation of household, government, and nonprofit institutions serving household sectors, as well as exports minus imports, are aggregated into a single column. The elements of value added are consolidated into a single row. An input–output table emphasizes the interrelationships between industries in an economy with respect to the production and uses of their products, including those imported from abroad. Table 1 illustrates the economy with each industry listed across the top as a consuming sector and down the side as a supplying sector.

Table 1. Simplified symmetric input–output table.

Empty Cell	**Industry 1**	**Industry 2**	**…**	**Industry n**	**Net final demand**	**Total output**
Industry 1	a_{11}	a_{12}	…	a_{1n}	Y_1	X_1

Empty Cell	Industry 1	Industry 2	…	Industry n	Net final demand	Total output
Industry 2	a_{21}	a_{22}	…	a_{2n}	Y_2	X_2
…	…	…	…	…		
Industry n	a_{n1}	a_{n2}	…	a_{nn}	Y_n	X_n
Value added	V_1	V_2	…	V_n		
Total output	X_1	X_2	…	X_n		

Source: Own elaboration adapted from National Insititute of Statistics.

The relationships in Table 1 can be read in rows as a system of *n* equations [51], whereas in matrix form as in Eq. (1).

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} x. \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} . \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} . \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} \tag{1}$$

In matrix form, x is the total output, A is the matrix of technical coefficients, B is the matrix of allocation coefficients, v is the primary inputs, and D corresponds to the final demand. An input–output table can be formalized as the sum of rows, as in equation 2a. Similarly, input–output tables can be read by columns where the sum of the rows of the matrix of allocation coefficients is a measurement of the forward linkages b_{ij}, as in equation 2b

$$2a: x = Ax + D;\ 2b: x = xB + v \tag{2}$$

Provided the values of the coefficients and demand are known, it is possible to solve this set of equations to find the level of X of various industries necessary to satisfy the specified level of demand. Straightforward manipulations lead to equation 3, where I stands for the identity matrix, which is a square matrix where all the diagonal elements are Eq. (1) and all other elements are equal to zero.

$$\begin{gathered} X - AX = D \\ (I - A)X = Y \\ X = (I - A)^{-1}D \end{gathered} \tag{3}$$

From equation 3, the Leontief matrix can be drawn [50], [52] as formalized in equation 4.

$$L = (I - A)^{-1} \tag{4}$$

To conclude, the Leontief matrix is instrumental in assessing the impact of an exogenous increase in demand on all the sectors that make up the A matrix. It highlights the technological interdependence of the production system and identifies the generation of output demand from final consumption that is part of the net final demand throughout the system.

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It is then possible to simulate the output levels required to meet changes in net final demand and consequently how output levels would have to change to meet the estimated changes in net final demand.

Several assumptions were made to simplify the analysis due to the structure of the data. We assumed constant technical coefficients, suggesting stable technology over the considered period. We hypothesized a closed economy model to focus on domestic implications. The parameters for sectoral interdependence refer to data from 2019, the latest available from the national accounting system. These assumptions may limit the external validity of this study. Although IOA has been widely used for accounting studies, its application in evaluating the social, economic, and environmental impacts of future scenarios has increased, yielding significant policy implications [45,54].

That being said, RQ1, which focuses on the technologies and the investments required to comply with the Green Deal decarbonization targets as reinforced by the Fit for 55, was addressed by reviewing documents and interviewing experts from the national business association. RQ2, which explores the socioeconomic consequences of the investments identified in RQ1, was addressed using the IOA. RQ3, concerning the emissions avoided due to investments in decarbonization, was answered by simulating emissions based on our results.

Consequently, the scenario was set. Scenarios are frequently employed, given that they can aid in exploring potential future alternative pathways to handle long-term concerns characterized by unpredictability and complexity [43]. Scenario analysis is useful for projecting a wide range of topics, such as production, consumption, trade, prices, investments, and technology mixes [55].

The economic impact is predicted for two scenarios: the RSNECP refers to the update of the Integrated Energy and Climate Plan scenario according to the latest available statistical data and the latest events affecting the energy system. The PSFF55 includes an update of socioeconomic drivers compared to the Integrated Energy and Climate Plan, the introduction of the COVID-19 pandemic effect on residential sector energy consumption and travel demand, hydrogen consumption as in the Italian hydrogen strategy, and the energy measures of the National Recovery and Resilience Plan. Fig. 1 summarizes the process followed to estimate the investments needed to comply with fit for 55 ambitious targets starting from available data contained in the national energy and climate plan updated with Green Deal information.

Fig. 1. Roadmap of scenario definition. Source: Own elaboration.

Due to the impacts of the pandemic and geopolitical crises, socioeconomic data were updated according to the latest forecasts from the National Statistical Institute. In addition, the goals of the national hydrogen strategy were factored in, as they impact renewable development. Accordingly, insights from a focus group composed of experts from different sectors were utilized to understand the impact and investment requirements. As follows and in the dedicated annexes, key information regarding the differences of the scenario with respect to the baseline are reported. In regard to the target for GHG emissions reductions, while the NECP aimed for a 40% reduction, our scenario targets a 50% reduction.

Considering the sectoral production and added value projections, higher growth is expected from 2020 to 2030 due to the National Recovery and Resilience Plan. This growth is partly mitigated by the effects of the Green Deal policy. See Annex 2 for details. With regard to the introduction of new processes for green fuel production, according to the industrial union's forecasts, the use of blue and green hydrogen production from RES is expected to increase marginally by 2030. Considering biomethane, BioLPG, and renewable dimethyl ether, the increasing use of biomethane in the civil sector, transport, industry, and electricity generation is assumed, with a maximum capacity of 0.77 million tons of oil equivalent (Mtoe) of BioLPG and 0.5 Mtoe of renewable dimethyl ether by 2030. For the role of biorefineries, it is assumed that existing refineries will be upgraded with a maximum processing capacity of 2 million tonnes of feedstock by 2030 for the production of hydrotreated vegetable oil (HVO), bionaphtha, and BioLPG. The total expected output is 1.8 Mtoe. Moving to the introduction of technical and policy inputs from business associations, an annual 1.5% increase in the building renovation rate is considered in light of recent national policy aimed at boosting energy efficiency and building performance. As per the energy efficiency target, savings are projected according to active measures compliant with Article 8 of the EED. Finally, Annex 3 resumes the annual GDP growth rates according to the baseline and the scenario that takes into consideration recent economic-impacting events.

Table 2 reports the estimated investment to run the analysis. Impact assessments on the electricity system refer to 2030. The scenario necessitates additional investment compared to the BASE scenario. It is important to recognize that even without new policy measures, the energy system will need investments to upgrade or replace aging technologies and facilities.

Table 2. Expected investments, € bn.

Technology	**RSNECP**	**PSFF55**	**delta**
RESIDENTIAL	115.8	153.7	37.9
Building rehabilitation (excluding installations)	18.8	36.9	18.1
Heat pumps	6.38	23.1	16.72
Heating, air conditioners and DHW	30.6	15.4	−15.2
Kitchen	3.3	6.3	3
Electrical equipment	56.7	72	15.3
DISTRICT HEATING (DISTRIBUTION)	0.9	1.5	0.6
TERTIARY	90	118	28
Building upgrading	0.8	11	10.2
Electrical equipment and lighting	41.3	43.3	2
Heating and DHW	5.1	6.7	1.6
Heat pumps	37.2	52	14.8
Kitchen	5	5.3	0.3
INDUSTRY	18.4	26.3	7.9
Electric motors and uses	1.2	1.7	0.5
Cogeneration and boilers	1.8	3.4	1.6
Efficiency processes (including heat recovery)	15.4	21.2	5.8
TRANSPORTATION	683	670	−13
Motor vehicles and motorcycles	579.5	539	−40.5

Technology	RSNECP	PSFF55	delta
Buses	22	35.3	13.3
Trucks	81.8	94.4	12.6
Hydrogen trains	0	1.5	1.5
ELECTRICAL SECTOR	41.1	99.4	58.3
Bioenergy	3.2	8.8	5.6
Fossils	10.3	4.1	−6.2
Geothermal	2.6	2.7	0.1
Hydroelectric	0.7	0.7	0
Photovoltaic	14.1	47.3	33.2
Wind power	10.2	35.8	25.6
SYSTEM	25	51.5	26.5
Transmission Electricity Grid Development	9.3	13	3.7
Electricity distribution networks upgrade	12.8	21	8.2
New pumping plants and dynamic acquisition systems	0	6.5	6.5
Hydrogen (production and transportation)	0	2.9	2.9
Refineries, biorefineries, green fuels	2	4.5	2.5
Electric charging infrastructure	0.9	3.6	2.7

Source: Own elaboration based on [20] and analysis of the RSFF55 hypothesis.

4. Results

The scenario necessitates a significant commitment in terms of incremental investment relative to a trending evolution of the energy system and the economy. It should be considered that even without additional policy measures, the energy system will have to incur investments to perform its normal functions due to the end-of-life of technologies and plants that will need to be replaced. Therefore, the cost attributable to decarbonization is the additional cost for more expensive investments or interventions not foreseen in the trend evolution.

Fig. 2 illustrates investments based on the RSNECP and PSFF55 scenarios, starting from the baseline where production is €3365.58 bn, intermediate imported inputs are €340.73 bn, added value is €1589.58 bn, and there are 32.35 million full-time equivalents. Implementing the planned investments would increase the final demand by approximately €974.2 bn between 2020 and 2030 in the RSNECP scenario. The overall impact on production would be €1753.6 bn, and in terms of employment, the effect would see an increase in standard labor units of 9.6 million.

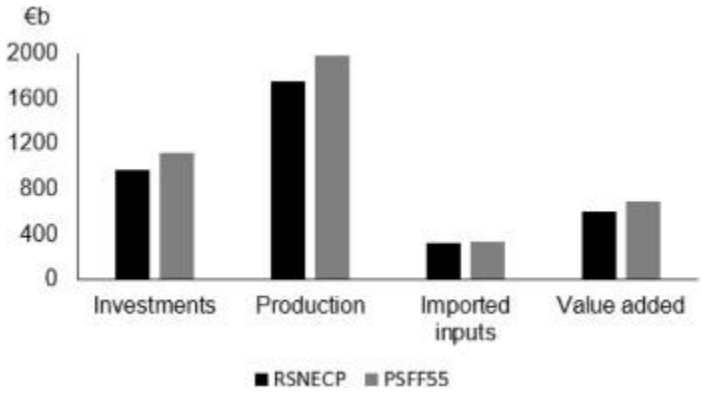

Fig. 2. Effects on the national economy.

Source: Own elaboration. The delta reflect additional investments according to the scenario.

The increase in nominal value added would amount to €595.3 bn. In the PSFF55 scenario, investment and incentives to boost the supply of technology would amount to €1120.7 bn, with an increase in value added of €1976.1 bn and €1645.3 bn net of imported intermediate goods. There would be higher employment of 11.48 million full-time equivalents and an increase in value added of €689.1 bn. The gain attributable to additional investment in energy efficiency technologies in the PSFF55 scenario would be approximately €147 bn, with increases over the RSNECP scenario of nearly €222.5 bn in output, employment of 1.876 million full-time equivalents, and value added of approximately €938 bn.

Table 3 presents a detailed analysis at the sectoral level and allows for an assessment of each sector's contribution to the overall macroeconomic impact.

Table 3. Overall impact on the national economic system (2020–30).

Empty Cell	**Increased demand € bn**	**Production € bn**	**Intermediate imports € bn**	**Value added € bn**	**Full-time equivalent m**
Residential	153.85	264.38	39.58	100.08	1.696
Industrial	26.29	48.14	6.63	17.27	0.257

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Empty Cell	Increased demand € bn	Production € bn	Intermediate imports € bn	Value added € bn	Full-time equivalent m
Tertiary	118.43	198.44	33.48	73.98	1.183
Transportation	670.26	1175.507	226.94	384.31	6.055
Energy and Energy system	152.65	289.64	303.91	113.46	2.293
Total	1121.49	1976.1	330.82	689.11	11.483

Source: Own elaboration and adaptation from [20].

Considering the effects on the public budget and the assumed incentive mechanisms involved in implementing the various investments, the implications for the state budget could be quite significant, particularly in relation to tax revenue streams (both direct and indirect taxes).

With regard to direct taxes, we observe an increase in the tax revenues of manufacturing companies producing efficient goods and technologies, individuals, the labor force, and suppliers, even as taxes paid by energy companies decrease.

The overall net effect in terms of higher revenues amounts to €168.7 bn. On the tax side, the higher VAT revenue associated with the assumed increase in demand is estimated at €163.1 bn. According to our estimates, the impact on social contributions and residual categories of current and capital revenues is marginal. Additionally, we estimate a reduction in revenue from VAT and excise duties paid on saved energy, amounting to €12.1 bn. Considering the net effects on tax revenue components mentioned above, the total impact on the state budget becomes €529.5 bn over the 2020–2030 period, as shown in Table 4.

Table 4. Overall effects on public finance.

Item	**€ bn**
Investments	1121.49
Effect public finance	529.508
of which	

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Item	€ bn
Direct and indirect taxation	332.868
Other revenues	54.036
Excise and VAT (lower consumption)	−12.146
Social contributions	154.75

Source: Own elaboration.

Regarding the avoided costs resulting from lower energy consumption and lower emissions, a significant reduction in primary energy consumption from the 2019 level of approximately 30 Mtoe to 2030 emerges and amounts to 135 Mtoe cumulative by 2030, which is consistent with the yearly breakdown shown in Fig. 3. The reduction in primary consumption stems from the contraction in the use of fossil sources, specifically, the contraction in the consumption of coal and petroleum products, mainly due to the divestment of coal from the power sector, the contraction in the consumption of natural gas due to the efficiency of thermal uses, and the electrification of final consumption. The cumulative avoided emissions by 2030 are expected to be 342 Mtons more than the RSNECP.

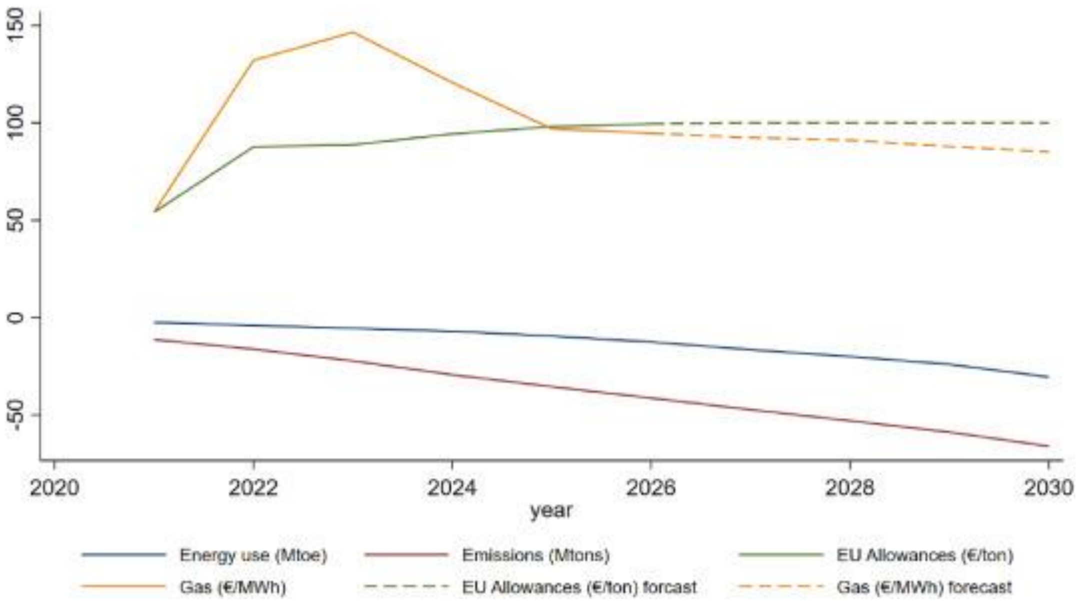

Fig. 3. Avoided consumption and environmental market prices.

Source: Own elaboration and [20].

As a result of energy efficiency and the shift in demand from fossil fuels to renewables, energy dependence on fossil fuels is reduced in the PSFF55 to 59% in 2030; consequently, spending on energy imports is significantly reduced. To assess the effects of the PSFF55 energy expenses, we considered the evolution of fuel prices, as shown in Annex 4.

The increase in import prices, particularly gas prices, for the past two years was considered. For gas, we considered the projections of the Stated Policies scenario of the World Energy Outlook 2021 published by the International Energy Agency, while for other sources, we referred to the forecast of the EU Reference Scenario, which is one of the EC's analysis tools in the area of climate action.

According to our estimates, the national energy bill in 2030 will contract by nearly 50% from its 2019 value, despite economic growth and rising prices of the main commodities under consideration. Reducing energy dependence is the main driver of this contraction and is driven by energy efficiency, a fuel switch to locally produced renewables, increased production capacity of domestic biorefineries, and a recovery in domestic natural gas supply.

The main reduction in the energy bill appears to be related to petroleum products, with more than €13 bn less in the bill, a trend pertaining both to the decline in consumption and to the assumption that exports will remain similar to those of recent years. Expenditure on gas imports shrinks by €4 bn (approximately 30% less) in the face of a 37% reduction in gas consumption, while spending on coal tends to zero, mainly because of its phaseout.

The contraction of fossil sources in the PSFF55 produces another economically quantifiable effect—avoided emissions, as shown in Fig. 3. The economic impact on the energy system due to avoided emissions and reduced consumption is reported in Table 5; we estimated the positive impact to reach €66 bn in cumulative savings by 2030.

Table 5. Overall effects on the energy system (cumulative values 2020–2030).

Impact	**Source**	**Unit**	**Total**
Quantitative impact on the Energy system	Energy Saving	Mtoe	132
	Avoided emissions	Mt	380
Economic impact on the Energy system	Energy Saved	€ bn	29.925
	Avoided emissions	€ bn	36.1
	Total	€ bn	66.025

Source: Own elaboration. Amount calculated considering the reference values for commodities in Annex 4.

Based on the results of this article, we can summarize the added value. First, the article provides a holistic assessment of the techno-economic and environmental impacts of the Fit for 55 package using the Italian economy as a case study but with a replicable methodology. Such a comprehensive perspective is crucial for understanding the macroeconomic impact of environmental policies thanks to the integration of recent economic updates, the pandemic's effect on energy consumption, and other variables not typically combined in previous analyses. Second, the paper addresses the financial nuances of implementing the Fit for 55 package by estimating, among other variables, the expected return on public finances and the net investment cost. In addition to the economic aspects, the paper illustrates the costs avoided through emission reductions and energy savings and even highlights the potential environmental benefits. The paper then highlights the synergies between different policy instruments, emphasizing the importance of an integrated regulatory framework.

5. Discussion

Studies evaluating policy instruments' technical and socioeconomic outcomes are difficult to compare, but understanding how different policy instruments can be designed to reduce trade-offs between different outcomes is important [56]. Notably, the economic implications of decarbonization policies have emerged as a crucial point of debate in climate change [57]. These studies are important to understand how specific sectors are positively impacted, for example, by creating jobs and technological innovations, or negatively impacted, e.g., by fossil fuels in energy-intensive industries [58]. From the results, it is possible to compare the required investments with the benefits of increased revenue for public finance and the value of energy saved and avoided emissions. From a public finance perspective, the room for maneuvering on the fiscal side is linked to a potential €529bn return. This magnitude can be interpreted as an estimate of the financial availability to adopt policies to boost investment demand through general taxation and other intervention measures to offset indirect costs, thereby mitigating the social cost of the transformation induced by the Fit for 55 package.

Considering the potential revenue for public finance and the avoided costs in terms of energy saved and lower emissions, the total benefit reaches €596 bn. As a result, the overall net investment cost is €527bn.

Despite the advantages of IOA, the study has some limitations following the assumptions made prior to data analysis. We assumed constant technical coefficients, thus assuming a constant linear relationship, excluding the assumption of increasing or decreasing returns to scale. We also assumed that the level of technology would be stable over the period considered. However, this is plausible in the short run, as knowledge accumulation becomes significant over time, making production systems dynamic. We also assumed a closed economy model since IOA does not necessarily identify additional values in VA, output, or employment, given the system constraint that sees the net effect ruled out in the presence of saturated production capacity. Although this could result in biased outcomes, it should be noted, however, that technological and structural changes occur slowly in mature industrial systems; thus, the abovementioned assumptions do not alter the results significantly, so the internal validity holds. However, it must be taken into consideration that the results can differ significantly from country to country since they are strongly influenced by the industrial structure of the economy being analyzed, so the external validity is trustworthy for countries with similar economic conditions.

The policy implications are twofold: policymakers can benefit from our results on the macroeconomic impact of Fit for 55 as support for a broader assessment of the long-term costs and benefits of public spending to support investments in the decarbonization of the economy. Our results can also help them understand how the expected investments will impact the different sectors, both in terms of production and added value as well as in terms of new employment. Policy options on climate targets interact in many ways, especially in the context of the carbon market and policies to increase energy efficiency; for example, energy-saving policies also allow the share of renewable energy in total energy consumption to increase without affecting RES capacity. Policies promoting the replacement of fossil fuels with RSE result in both a reduction in greenhouse gas emissions and primary energy consumption. Policies aimed at electrifying end-use sectors help reduce final energy consumption and create an additional impetus for RES supply. Transport policies that address carbon and other externalities all positively impact the transport system's efficiency and contribute to the overall energy efficiency performance and GHG reduction. Nearly zero-energy building requirements promote high-energy performance buildings with low energy consumption provided largely by renewable energy. Thus, it is important to ensure coherence between policies, as the interactions resulting from policy options can only be properly assessed within an integrated regulatory framework [12,59]. Indeed, the synergetic effect of various policy instruments can result in more value compared to the sum of individual implementations [60]. However, the implementation of overlapping policy tools may lead to unsatisfactory output [61].

Future research should focus on two issues. First, further studies using the same approach, as it is an approach widely found in the literature, are needed to obtain comparable results for other EU countries. This would generate additional value for policymakers and investors, both public and private. Second, it is important to focus on the implications of recent EU energy and climate policy developments introduced in the REPowerEU plan because global energy market disruptions could lead to further increases in decarbonization targets. Third, more research is needed to test potential setbacks from the implementation of such high-level and challenging policies, such as those on well-being, as concerns have emerged in the relationship between energy saving and welfare that may unevenly impact EU countries [30] or cause political delays given that achieving targets as set out in the Fit for 55 packages, particularly in the deployment of renewable sources, is critically dependent on the timely availability of power transmission and distribution networks [62].

6. Conclusion

Decarbonizing energy and production systems is imperative for sustainable development, and this paper delves into the economic and environmental impact analysis of recent European climate policies focusing on the Fit for 55 package requirements.

The paper aims to understand in what sectors and the amount of investments required to comply with the Green Deal decarbonization targets boosted by the Fit for 55, the socioeconomic consequences of meeting such targets, and environmental issues in terms of avoided emissions and costs due to investments in prominent decarbonization technologies.

Regarding the financial trajectory, the revised growth forecasts show that due to the influence of 'Fit for 55′ on the added value of various sectors, anticipated investments in residential, district heating, tertiary, industry, transportation, and electrical systems are set to ascend from €974.2 bn to €1120.4 bn, an increase of 15.07%.

The economic analysis revealed that there is expected to be a robust escalation in demand to €1121.49 bn and a boost in production to €1976.1 bn, with intermediate imports marking €330.82 bn, value added of €689.11 bn and 11,483 full-time jobs.

From an environmental perspective, this research estimates the potential avoided emissions to be approximately 380 million tons. Additionally, a noteworthy energy savings of 132 Mtoe was projected.

However, it is imperative to consider the evolving dynamics. With the backdrop of challenges in the global energy market and emerging EU energy and climate policies, it is plausible that there could be an uptick in decarbonization targets. Thus, our recommendation for subsequent research would be to delve into the ramifications of policies promoting the indigenous production of pivotal decarbonization technologies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Annexes.

Annex 1. Symmetric input-out framework with 63 Italian activities.

Code	63 Industries NACE rev 2	↕ 63 Industries	Output (1)	Families, Institutions, PA	Changes in inventory	Investments	Export	Total final demand (2)	Output (1 + 2)
V01	Plant and animal production, hunting and related services	…	46,070	18,268	−37	426	6369	25,063	71,133

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Code	63 Industries NACE rev 2	↕ 63 Industries	Output (1)	Families, Institutions, PA	Changes in inventory	Investments	Export	Total final demand (2)	Output (1 + 2)
V02	Forestry and forestland use	...	1111	804	733	733	159	1697	2808
V03	Fishing and aquaculture	...	1047	1693	4	56	212	1961	3009
VB	Mining and quarrying	...	41,334	6377	279	704	894	7976	49,310
V10_12	Food, beverage and tobacco industries	...	71,047	66,951	409	995	35,320	103,266	174,313
V13_15	Textile industries, Manufacture of clothing and leather goods	...	38,001	28,801	27	1492	48,325	78,618	116,619
V16	Manufacture of wood and cork, except furniture; articles of straw	...	13,007	2158	−282	618	2634	5410	18,417
V17	Manufacture of paper and paper products	...	20,769	4167	14	159	6696	11,022	31,791
V18	Printing and reproduction on recorded media	...	10,499	732	44	148	731	1612	12,111
V19	Manufacture of coke and refined petroleum products	...	30,041	15,065	133	206	14,594	29,865	59,905
V20	Manufacture of chemical products	...	52,403	4809	−21	966	26,758	32,533	84,936
V21	Manufacture of basic pharmaceutical products and preparations	...	17,039	10,061	128	1164	17,989	29,214	46,254
V22	Manufacture of rubber and plastic products	...	33,868	5089	−203	975	15,968	22,032	55,899
V23	Manufacture of other nonmetallic mineral products	...	25,077	1635	−917	−297	10,438	11,776	36,853
V24	Metallurgical activities	...	65,128	1416	−191	395	28,106	29,916	95,044
V25	Manufacture of metal products, except machinery and equipment	...	70,267	3815	−173	6920	22,963	33,698	103,965
V26	Manufacture of computers and electronic and optical products	...	15,266	6294	102	9913	12,206	28,413	43,679
V27	Manufacture of electrical equipment	...	25,253	5072	−344	4787	22,530	32,390	57,643
V28	Manufacture of machinery and equipment n.e.c.	...	51,281	4817	550	29,178	78,723	112,717	163,998
V29	Manufacture of motor vehicles, trailers and semitrailers	...	27,150	26,816	−82	15,990	33,177	75,983	103,133
V30	Manufacture of other transport equipment	...	12,083	2493	2354	9905	15,080	27,479	39,562
V31_32	Manufacture of furniture; other manufacturing industries	...	18,611	11,286	928	5761	22,518	39,565	58,176
V33	Repair and installation of machinery and equipment	...	10,922	779	−6	8677	2749	12,206	23,128
VD	Electricity, gas, steam and air conditioning supply	...	75,801	19,492	13	1306	380	21,178	96,979
V36	Water collection, treatment and supply	...	5512	6187	−1	396	29	6612	12,125
V37_39	Sewerage; waste management; materials recovery; sanitation	...	28,201	5552	−16	260	1046	6859	35,059
VF	Construction	...	66,016	10,785	−66	116,106	1987	128,878	194,893
V45	Wholesale and trade and repair of motor vehicles/motorcycles	...	19,456	19,563	−1	3009	5735	28,307	47,762
V46	Wholesale trade, excluding that of motor vehicles and motorcycles	...	90,319	69,738	267	18,505	19,647	107,890	198,209
V47	Retail trade, excluding that of motor vehicles and motorcycles	...	23,490	97,375	441	10,138	12,037	119,550	143,040

Code	63 Industries NACE rev 2	↕ 63 Industries	Output (1)	Families, Institutions, PA	Changes in inventory	Investments	Export	Total final demand (2)	Output (1 + 2)
V49	Land transport and pipeline transport	...	68,219	27,373	18	1801	3840	33,014	101,233
V50	Sea and water transport	...	3716	5715	1	158	3359	9233	12,949
V51	Air transportation	...	7627	7703	−1	65	2472	10,239	17,866
V52	Warehousing and transportation support activities	...	57,257	14,633	6	1412	6090	22,136	79,392
V53	Postal services and courier activities	...	6165	656	0	60	872	1588	7753
VI	Accommodation services; food service activities	...	28,952	97,227	8	113	81	97,421	126,373
V58	Publishing activities	...	3421	3488	−2	1217	1010	5715	9136
V59_60	Film, video, music, sound and television program production	...	8929	5790	−76	944	1032	7767	16,696
V61	Telecommunications	...	24,374	14,206	−94	1858	4416	20,480	44,854
V62_63	Programming, computer consulting and related; information services	...	39,819	4197	−47	21,909	4758	30,864	70,683
V64	Financial services (excluding insurance and pension funds)	...	66,293	14,531	−1	779	4077	19,388	85,681
V65	Insurance, reinsurance and pension funds, excluding social insurance	...	10,193	19,462	0	158	1165	20,786	30,978
V66	Activities auxiliary to financial services and insurance activities	...	27,576	2558	0	177	2110	4845	32,421
VL	Real estate activities	...	58,798	178,583	0	8744	1150	188,477	247,275
V69_70	Legal and accounting; head office activities; management consulting	...	75,333	5370	51	3360	2734	11,464	86,797
V71	Architectural and engineering firm activities	...	27,176	1725	−162	3260	1578	6563	33,739
V72	Scientific research and development	...	4353	4126	22	12,850	2078	19,054	23,407
V73	Advertising and market research	...	18,231	168	−28	52	1427	1647	19,877
V74_75	Professional, scientific and technical activities; veterinary services	...	23,021	3490	6	442	2696	6628	29,649
V77	Rental and leasing activities	...	17,640	1054	−30	277	2249	3580	21,220
V78	Personnel search, selection, supply activities	...	13,007	791	0	59	936	1786	14,793
V79	Travel agencies, tour operators and reservation services	...	7951	6789	−5	16	1037	7842	15,793
V80_82	Investigation and security, building and landscape; business support	...	62,404	6971	−5	291	4355	11,617	74,021
VO	Public administration and defense; compulsory social insurance	...	19,526	129,602	106	795	942	131,339	150,865
VP	Education	...	8027	72,326	2	163	148	72,637	80,664
V86	Health services activities	...	15,229	123,324	44	818	682	124,824	140,053
V87_88	Social assistance	...	8656	18,189	1	37	15	18,241	26,897
V90_92	Creative and entertainment; library and archives; betting and gambling	...	12,114	13,141	216	800	440	14,381	26,495
V93	Sports, entertainment and amusement activities	...	10,589	8824	22	87	314	9225	19,814
V94	Activities of membership organizations	...	3688	6479	7	108	44	6631	10,319
V95	Repair of computers and personal and household goods	...	1837	1351	0	338	307	1997	3834
V96	Other personal service activities	...	4029	25,282	43	101	181	25,564	29,593

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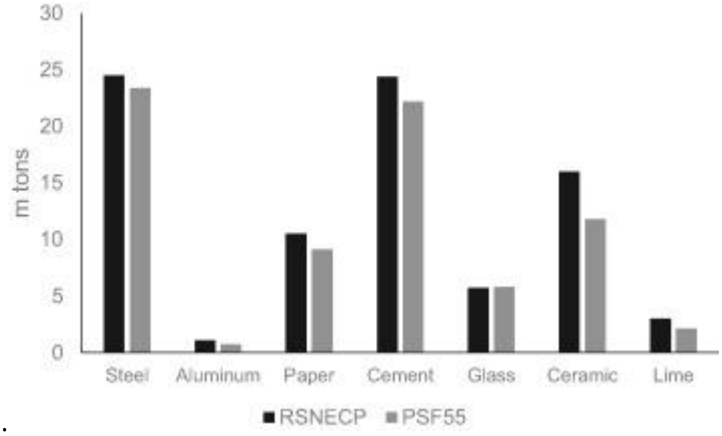
Code	63 Industries NACE rev 2	↕ 63 Industries	Output (1)	Families, Institutions, PA	Changes in inventory	Investments	Export	Total final demand (2)	Output (1 + 2)
VT	Household and personal activities for own use	...	0	18,026	0	0	0	18,026	18,026
V	Intermediate consumption at basic prices	...	1,750,217	1,301,238	4187	312,842	524,600	2,138,680	3,888,897
	Taxes minus subsidies on products	...	39,404	130,435	312	14,861	580	145,876	185,280
	Total intermediate consumption/Final consumption at purchaser prices	...	1,789,621	1,431,673	4500	327,703	525,180	2,284,556	4,074,177
	Value added at basic prices	...	1,611,369						
	Output at basic prices	...	3,400,989						
	CIF imports	...	487,908						
	Total resources at basic prices	...	3,888,897						

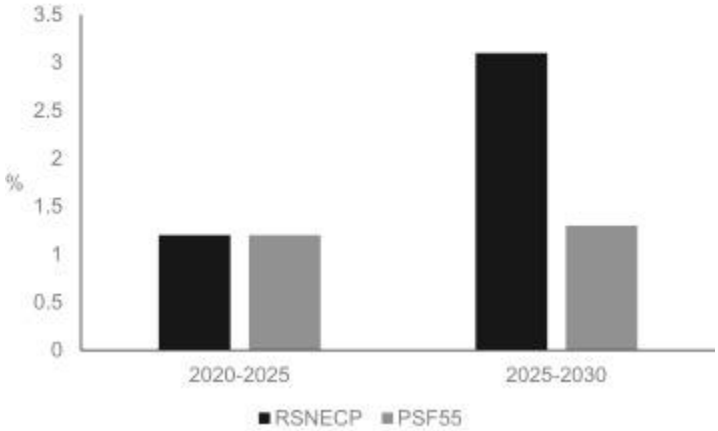
Source: Own elaboration based on National Institutes of Statistics National Accounts.

Annex 2. Projection of industrial production of prominent energy-intensive sectors in 2030 under the baseline



and policy scenarios.

Annex 3. Average annual GDP growth rates under the baseline and scenario hypotheses.



Annex 4. Evolution of international energy commodity prices (€2015/toe).

Empty Cell	**2020**	**2025**	**2030**
Oil	33.5	52.8	72.2

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Empty Cell	**2020**	**2025**	**2030**
Gas	20.8	29.9	38.1
Coal	8.9	12.3	15.6

Source: World Energy Outlook 2021 and EU Reference Scenario.

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