IT 2015 Report

pathways to

deep decarbonization

in Italy

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SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

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Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP), an initiative of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their energy systems by 2050 in order to achieve a low-carbon economy and significantly reduce the global risk of catastrophic climate change. Built upon a rigorous accounting of national circumstances, the DDPP defines transparent pathways supporting the decarbonization of energy systems while respecting the specifics of national political economy and the fulfillment of domestic development priorities. The project currently comprises 16 Country Research Teams, composed of leading research institutions from countries representing about 70% of global GHG emissions and at very different stages of development. These 16 countries are: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

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SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
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The Sustainable Development Solutions Network (SDSN) was commissioned by UN Secretary-General Ban Ki-moon to mobilize scientific and technical expertise from academia, civil society, and the private sector to support of practical problem solving for sustainable development at local, national, and global scales. The SDSN operates national and regional networks of knowledge institutions, solution-focused thematic groups, and is building SDSNedu, an online university for sustainable development.

ENEA

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- Nuclear Energy ,
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ENEA's participation in this project involves the Studies and Strategies Central Unit (UCSTUDI) whose activity is focused on energy and sustainable economic development at the national and global levels. UCSTUDI provides public and private decision-makers with analyses and evaluation elements allowing them to develop governance strategies and tools in their fields of interest, consistently with the national and European policies and directions. The Unit is active in: energy technology watch and technological perspectives for sustainability; techno-economic analysis of the energy and the economic system through model representation and elaboration of quantitative scenarios; Analysis of social aspects of technology diffusion and innovation processes.

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The research for this report was conducted by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the Fondazione Eni Enrico Mattei (FEEM).

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Contents

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in Italy

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Executive summary

This report contributes to the national debate on climate-change mitigation, and the importance of deep decarbonization, by examining three alternative pathways that could reduce Italian CO_2 emissions by at least 40% in 2030 and 80% in 2050, compared to 1990. It analyzes the challenges the Italian energy system faces, and possible future technological developments that will need to be pursued. We answer four key questions:

What are the key challenges and uncertainties that Italy needs to address and overcome to foster a deep decarbonization process?

Italy has some idiosyncratic features in its natural resource endowments, and its geographic, social, and economic factors. These represent barriers to achieving deep decarbonization. The country has small coal deposits, orographic features that limit railroad transports, some renewable sources that are already fully exploited (e.g. hydrogeological sources), and others that are difficult to exploit for geographic reasons (e.g. few suitable areas for offshore wind generation). As a result, Italy has historically experienced a higher share of gas and oil products, and a lower share of coal, in the energy mix compared to average EU levels. Furthermore, Italy heavily relies on imported fuels.

About 80% of Italy's energy used is imported. Hence, deep decarbonization represents a chance to reduce pressure on the environment, and also an opportunity to lower energy dependence and exploit some available natural resources. For example, the recent penetration of renewable energy technologies has already significantly reduced energy dependence.

Several technological, social, and economic challenges will have to be addressed to design feasible deep decarbonization pathways:

(i) the limited social acceptability of some options, in particular carbon capture and storage (CCS), which is subject to the "not-in-my-backyard" (NIMBY) syndrome that seems to arise with large energy projects;

(ii) obstacles to further increasing the use of some renewable sources, mainly domestic biomass and large hydro, and also off-shore wind and ground installations of solar energy that compete with agricultural land;

(iii) the insufficient technological ability to manage the variability of power generation from some renewable sources;

(iv) the current lack of CCS technologies at reasonable costs.

What will the impacts of deep decarbonization be on the energy system, the economy, and society? What will the related investment costs be? What will the impacts be on income and employment?

To provide a deeper understanding of the feasibility of Italian decarbonization targets and the related costs, the report presents three alternative pathways to achieve deep decarbonization, or an 80% GHG emission reduction by 2050 compared to 1990 levels. The three pathways differ in their underlying assumptions about which ones of various technologies will be available, and able to penetrate the Italian energy system. It does this by postulating different assumptions on the cost of technology, the availability of renewable sources and of carbon capture and storage (CCS), the social acceptability of renewable generation technologies and CCS, and administrative barriers.

The decarbonization scenarios have been produced by combining insights from a very detailed bottom-up energy system model (TIMES-Italy), with two top-down Computable General Equilibrium (CGE) models (GDyn-E and ICES). TIMES-Italy provides insights on the transformation required by the Italian energy system, while GDyn-E and ICES allow studying the macroeconomic implications of such an energy transformation.

To reduce domestic emissions by at least 80% (compared to 1990) in 2050, a smooth and efficient transition is needed. All three DDPs achieve energy and process emissions below 90 $MtCO_2$, or 1.5 tCO_2 per person. In the analysis of these energy scenarios, emissions reductions are driven by a drastic decrease in the carbon intensity of energy (3.0% to 3.2% average annual rate - a.a.r). Renewable sources and electricity (electrification of final consumption up to 46%) progressively replace fossil fuel consumption (30% to 35% of fossil fuel consumption in 2050), and improvements in energy efficiency reduce further their demand. The faster or slower development of CCS determines the long-term role of solid fuels. Limiting fossil fuel role has significant impacts on energy source diversification and energy security: while in 2006 Italian import dependence reached 87%, in 2050 it may drop to below 30% to 35%.

One of the most important drivers of deep decarbonization is an almost total decarbonization of power generation processes (which translates into a -96% decrease in their emissions in 2050 compared to 2010 level). In the DDP scenarios analyzed, renewable energy sources (RES) provide growing shares of power generation (up to 93% in 2050) and the contribution of variable RES expands after 2030. These variable RES account for 55% to 58% of total net generation in 2050.

At the same time, end-use technologies efficiency is crucial to achieving the 2050 targets in all DDPs.

The DDPs require considerable effort in terms of low-carbon resources and technologies. They also require considerable effort in economic terms. The cost changes, compared to a Reference Scenario, are significant: up to 30% higher cumulative net costs over the period 2010-2050. In particular, the emphasis switches from fossil fuel costs and operating costs towards investments in power generation capacity and more efficient technologies and processes.

The macroeconomic analysis points at increasing decarbonization costs, in line with cost estimates for other EU countries. Such costs do not vary significantly across the three alternative pathways; they range between 7% and 13% of gross domestic product (GDP) relative to the reference scenario. All DDP scenarios estimate per capita GDP to grow over the examined period although less rapidly when decarbonization policies are implemented. The average annual growth rate of GDP in the 2010-2050 period is expected to be between 1.17 and 1.25% in the reference case. With decarbonization policies the growth rate would be between 0.18% and 0.35% slower. Modeling analysis suggests that decarbonization is likely to induce a structural change in the economy that could benefit both the electricity generation sectors and energy-intensive industries. This structural change will also determine employment reallocation across sectors, from fossil fuel extraction, refining, and commercialization towards renewable energy generation and energy intensive industries (+15% and +25% employment in 2050).

Are currently available technology options sufficient to achieve this target? What will be the role of international technology cooperation?

The DDPs presented in this report rely on the deployment of already available or close-to-the-market technologies. Hence, the technical feasibility of the transformation scenarios is high. Still, some technical hurdles remain to be addressed. High among them are the management of variable renewable energy and concerns over the contribution of biomass. Furthermore, challenges exist with respect to the deployment of CCS technologies.

What policy support will need to be established to successfully achieve deep decarbonization?

In past decades, Italy adopted several policy instruments to support the deployment of RES and the achievement of energy-efficiency targets (green certificates, feed-in tariffs, investment subsidies, tax deductions, etc.). These instruments allowed important successes to be achieved, such as increasing the share of renewables in Italy's primary and final energy consumption, and improving overall energy efficiency. However, the DDPs in this Report illustrate, achieving the deep decarbonization and modernization of the Italian energy system will require a much stronger effort, in terms of technology development and even more focused policy planning.

There is a need to learn from national best practices, and improve policy implementation to contain the costs of an energy transition for producers, consumers, and the public sector. High subsidies, such as those granted so far, are no longer necessary to increase the deployment of certain renewable technologies. If subsidies are granted, they should be targeted towards technologies that present the greatest benefits, but which are likely to encounter the most significant obstacles.

In any scenario characterized by higher electrification and higher penetration of variable renewables, investments in the overall strengthening and modernization of the power grid

is crucial. This would allow Italy to exploit the full potential of electric renewables, while improving service quality. It is therefore necessary to create a better framework to foster the necessary level of investment.

In light of limited public budgets, a key requirement for modernizing the Italian energy system is mobilizing private capital, and guaranteeing access to credit for firms and households. A clear regulatory context, streamlined administrative procedures, the intelligent use of public guarantee schemes, framed by a stable long term policy orientation (although admitting adjustments and corrections of the course adopted), would give investors a positive indication about the future for their returns on investments, limiting policy and regulatory risk.

Public-Private Partnership agreements (PPPs) should be strongly encouraged to assure that important private capital investment is available, provide the necessary public guarantees, and offer the private sector's technology innovation and management expertise in project financing.

Appropriate normative frameworks for the operation of energy service companies (ESCOs) could help fund the renovation of public and private buildings and condominiums for better energy efficiency or greater penetration of electric or thermal renewable energy sources.

A transparent framework for involving citizens and local communities in decisions about large energy infrastructure projects is a key element to realize many renewable technologies and projects, and to develop technologies like CCS. This would facilitate public understanding of the actual risks, local costs, and benefits of a given energy technology or project.

Designing a national industrial development strategy, aimed at the progressive decarbonization of the economy and the efficient use of all resources, would set a path for the transition of the Italian energy system. The strategy should strengthen the material and human research infrastructure, developing technologies and products coherently with the decarbonization perspective, and accelerating the innovation process to enhance competitiveness.

At the core of such a strategy should be a renewed effort at all levels of the RD&D chain, including higher education, training, and basic research. Development of new energy and enabling technologies or materials is necessary for less carbon- and resource-intensive production of goods and services. International research cooperation in technology areas critical to a low-carbon transition (CCS, offshore wind for deep water applications, energy efficiency, energy storage technologies, etc.) would be beneficial.

Public research spending needs to return to levels closer to EU averages, with a firm government commitment to enabling policies and to complement private funding in those stages of research where it is sub-optimal.

1 Introduction

1.1 The Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP) is a collaborative global initiative convened by the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI). Its objective is to improve the understanding of possible transition paths that different countries can take to achieve a very low carbon economy, with the aim of collectively limiting the increase in global mean surface temperature to 2 degrees Celsius (°C), as internationally agreed.[1]

For policymakers to adopt sustainable decisions and for citizens to understand the choices and the risks at stake, both at the international and at the national level, it is crucial that they have a full grasp of the challenges that deep decarbonization paths entail.

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the Fondazione ENI Enrico Mattei (FEEM) joined this initiative in October 2014 to contribute to the discussion on decarbonization pathways by providing insight on feasible strategies for Italy.

1.2 Background and Objectives

The debate on long-term decarbonization strategies in Italy has been mostly confined within the circles of environmental activists, non-governmental organizations (NGOs) such as the World Wildlife Fund (WWF), the Kyoto Club, and Legambiente, and a few research organizations, think-tanks and universities (like ENEA[2], FEEM[3], University of Siena[4], CMCC[5]). Some businesses have started strategic thinking and planning on long-term decarbonization as well: those that have identified concrete opportunities for growth in doing so. They include power producers, and manufacturers and installers of renewable energy systems and components.

Only recently has the debate become an agenda item for policymakers. The national government's stance has been more reactive than proactive. In 2013, Italy prepared a National Energy Strategy (NES) [6]. In this document the 2011 Energy and Climate Roadmap to 2050 of the European Commission[7] and the 2°C goals of the EU were considered long-term aspirational goals. The NES was focused on a 2020 horizon, and on meeting or improving the EU 2020 Climate and Energy Package targets

1 See UNFCCC/CP/2009/L.7. Copenhagen Accord. 18 December 2009, p.2

2 Virdis, Gaeta *et al.*(2014) Verso un'Italia low-carbon: sistema energetico, occupazione, investimenti. Rapporto Energia e Ambiente volume Scenari e Strategie. 2013 http://www.enea.it/it/produzione-scientifica/rapporto-energia-e-ambiente-1/rapporto-energia-e-ambiente-scenari-e-strategie-2013

3 Knopf et al. (2013, 2014); Massetti E. (2012); Bosetti V., Catenacci M. (2015)

4 The University of Siena as hub of the Mediterranean SDSN (Sustainable Development Solutions Network). See Borghesi et al. (2015a,b); Bastianoni et al. (2014); Caro et al. (2014); Antonioli et al. (2014)

5 Bosello F., Campagnolo L., Eboli F., Parrado R., (2012); Bosello, F., Campagnolo, L., Carraro, C. Eboli, F., Parrado, R. and Portale, E. (2013)

6 Italy's National Energy Strategy: for a more competitive and sustainable energy, March 2013, Ministero per lo Sviluppo Economico. http://www.encharter.org/fileadmin/user_upload/Energy_policies_and_legislation/Italy_2013_National_Energy_ Strategy_ENG.pdf

7 See Roadmap for moving to a competitive low carbon economy in 2050 (COM(2011)112), and Energy Roadmap 2050 (COM/2011/885) both of 2011, illustrating possible pathways for the EU to achieve an 80% GHG emission reduction with respect to 1990 by 2050.

for Italy. [8] Only the last chapter of the NES was devoted to the long-term perspective and to the specific challenges of the Roadmap to 2050 for Italy.

Specifically, the NES focused on 4 main objectives:

i.) Significantly reducing the energy cost gap for consumers and businesses, compared to Italy's European counterparts.

ii) Achieving, and exceeding, the environmental and decarbonization targets of the EU 2020 Climate and Energy Package.[9]

iii) Improving the security of Italy's energy supply.

iv) Fostering sustainable economic growth.

These objectives were broken down into 7 priorities and translated into several measures, with 2020 envisioned as the time horizon to achieve them. If fully implemented, the NES would help Italy lower its longer-term carbon emissions, but would certainly be insufficient to put her on a trajectory of 80% greenhouse gas (GHG) reduction to 2050, compared to 1990. This is what we refer to as deep decarbonization.

In October 2014, the European Council agreed on a 40% reduction in emissions by 2030.[10] This prompted interest in assessing the feasibility of such a target for Italy, its costs, and its impacts on the Italian economy. In the run up to COP 21, and as negotiations intensify around a European burden-sharing agreement for sectors not included in the Emission Trading Scheme (ETS) , interest can be expected to grow, helping focus minds on the challenges ahead.

Unfortunately, most citizens are very little involved, if at all, in this debate and in the decision-making process. This is a concern since, by definition, these processes will shape our common future and likely require active participation from all stakeholders. Coherent outreach strategies are missing, both on the political side and on the scientific side. There is certainly a pressing need to disseminate information on the deep changes that the transition to a low-carbon economy will require. The outreach must involve all stakeholders, especially the business sector which needs to perceive the decarbonization pathway as a modernization of the energy system and, as such, as an opportunity for growth and competitiveness.

The purpose of this report is to help focus the national climate-change mitigation debate on the importance of defining 2050 deep decarbonization pathways. To this end, the report provides answers to questions such as:

- What are the key challenges and uncertainties that Italy needs to address and overcome to foster a deep decarbonization pathway (characterized here as a process that achieves at least the target of 80% GHG emission reduction by 2050 compared to 1990 levels)?
- What impacts will deep decarbonization have on the energy system, the economy and society? What are the related investment costs? What are the impacts on income and employment?
- Are currently available technology options sufficient to achieve the deep decarbonization target?
- What policy support will need to be established to successfully achieve deep decarbonization?
- What will be the role of international cooperation in technology and/or policy?

This report examines three alternative deep decarbonization pathways to reducing Italian CO_2 emissions by at least 40% by 2030 and 80% by 2050, compared to 1990, in line with the EU 2030 objectives and the Roadmap to 2050. By design,

8 During the NES preparation, ENEA was responsible for the production of the NES scenario and some Roadmap scenarios to 2050

9 19-20% of RES share in final energy consumption, Italy's National Energy Strategy: for a more competitive and sustainable energy, March 2013, Ministero per lo Sviluppo Economico. pp 4

10 See, COM(2014)15 A policy framework for climate and energy in the period from 2020 to 2030, and the Conclusions of the European Council of 23-24 October 2014.

all three pathways reach energy and process emissions below 90 $MtCO_2$, representing 1.5 tCO_2 per person at the end of the period. But they do so in different ways, each of which implies different energy-system structures or different economic structures. The report will illustrate and discuss these different scenarios in the coming chapters. Specifically, we will assess their macroeconomic impacts by focusing on implications for growth, employment, and competitiveness.

Section 1.3 illustrates the modelling approach used to quantify the three techno-economic scenarios and their macroeconomic consequences. Section 1.4 briefly characterizes the Italian energy system and current trends in supply, demand, and related emissions.

Chapter 2 describes the pathways, discusses the criteria used to define the storylines, and reports on the energy and technological characteristics of those scenarios, as assessed by the bottom-up model TIMES. Chapter 3 presents the macroeconomic impacts of the three scenarios, based on two macro-economic general equilibrium models. Chapter 4 draws overall conclusions, highlights policy implications, and provides recommendations.

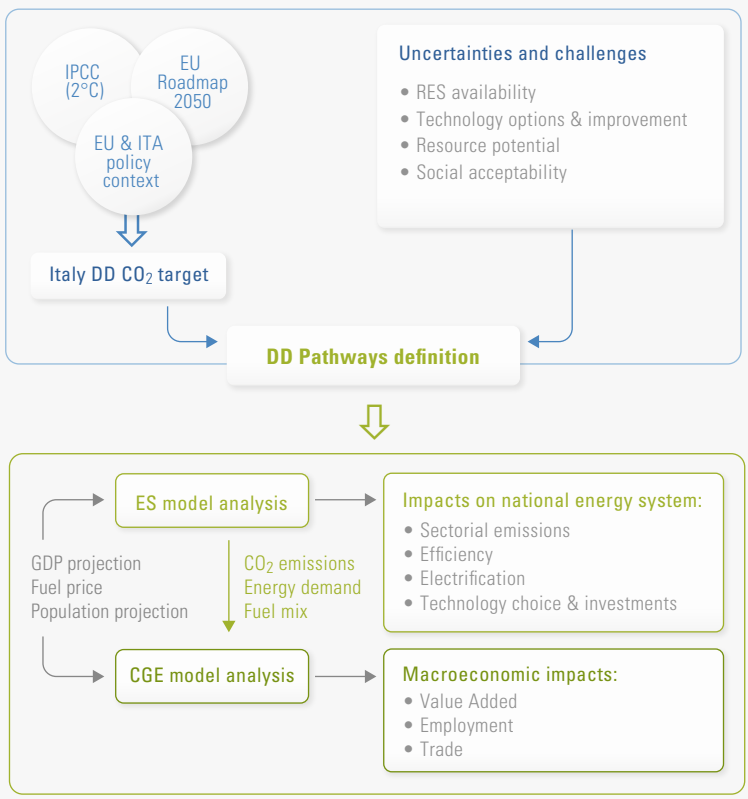
1.3 Methodology and Approach

The methodological approach used to characterize the deep decarbonization pathways for the Italian energy and economic system has been articulated in four stages. The following is a brief description of each of those stages:

- **Stage 1:** Overview analysis of the Italian energy system to identify key uncertainties and challenges and to define consistent storylines for the three decarbonization scenarios.
- **Stage 2:** Definition of the macroeconomic drivers and CO_2 emissions for the reference and decarbonization scenarios.
- **Stage 3:** Bottom-up assessment and quantification of the main energy trends (e.g. primary energy supply, final consumption) and of the technologies available to implement the chosen scenarios, performed using the energy system model TIMES-Italy.
- **Stage 4:** Top-down macroeconomic evaluation of the decarbonization scenarios using the GDyn-E and ICES CGE models. This is implemented by harmonizing drivers defined in Stage 2 with the output produced by TIMES-Italy in Stage 3. Relevant information, such as primary energy supply by source and emission reduction targets, are transferred from TIMES- Italy to the CGE models.

Figure 1 shows a schematic diagram of the modelling framework and how it links to the overall approach used in this report.

Figure 1 – Methodological approach



Source: ENEA and FEEM

The DDPP goal is to explore alternative decarbonization pathways that limit the increase in global surface temperature to 2 degrees Celsius (°C)[11]. The European Council (October 2009) supports an EU objective of reduce GHG emissions by 80-95% by 2050 compared to 1990 levels, in the context of reductions the IPCC says are needed by developed countries as a group. The Energy and Climate European Roadmap 2050 (both of 2011) identifies a European trajectory consistent with this target. For the exercise discussed in this report, we assume that Italy can follow a similar trajectory and contribute to achieving the 2°C goal by reducing its emissions about 80% in 2050 compared to 1990 levels.

In order to realize a consistent analysis of the Italian deep decarbonization pathway, it was necessary to characterize resource potential and availability (especially about RES, future technology costs and parameters) and all key variables that can affect the path of Italian decarbonization, identifying key opportunities and challenges, and discuss the associated uncertainties.

Given the many uncertainties and challenges and to ensure the robustness of deep decarbonization, the approach adopted proposes an analysis of multiple scenarios, taking into account three alternative pathways for Italy to reach the same emissions target.

In each of the three alternatives, one or more uncertainties/challenges have been highlighted, to understand how the Italian energy system can react, for example, to a higher or lower availability of renewable energy, or to a failure to deploy technology.

We use the TIMES-Italy energy system model to realize an energy assessment for each of the pathways. A cap on a maximum emissions level was imposed on the entire energy system, with no constraints on sectoral emissions. In the model, each scenario is characterized by different availability of resources, alternative rates of penetration by advanced technology, different policies, and varying degrees of public acceptance of different technologies.

The main drivers are gross domestic product (GDP), fuel prices, and population. Any projection into the future is inherently uncertain. For this analysis, exogenous assumptions on GDP and fuel price match those the European Commission used for the PRIMES 2013[12] scenario.

The level of electrification, energy intensity, technology deployment, and fuel mix are a result of the optimization process within the TIMES model.

The energy and macro-economic models used in this report are described in detail in the Appendix. However, some comments and caveats are necessary here to shed light on the boundaries of the analysis (i.e. what is explicitly taken into account and what is not).

The analysis focuses on CO_2 emissions: in its current version, the TIMES-Italy model does not consider all greenhouse gases (GHG) but only energy-related and process CO_2 emissions. Also, as land use and forestry activities are not included in the model, no specific assumption is made about the evolution of national CO_2 sinks to offset part of the emissions of the energy sector. Along the same lines, the TIMES-Italy model does not consider public transport infrastructure, power grid infrastructure, and their investment costs. These dimensions are included in the model by means of exogenous hypotheses about the development of public transport, and passenger-transport demand, or about the capability of the electricity system to handle intermittent renewables with higher management implicit costs than in the reference scenario.

Conversely, the TIMES-Italy model does not limit itself to technology options that are currently

11 IPCC, IInd Assessment Report, 1995

12 EU energy, transport and GHG emissions TRENDs TO 2050, Reference scenario 2013 – E3M-Lab for European Commission

commercially available. It takes into account likely technical improvements and economic developments that can reasonably be expected within the scenarios' time horizon.

Technologies like carbon capture and storage (CCS) associated with biomass are not included in this version of the TIMES-Italy model. Such a technology is indeed an important option for decarbonization, as it can lead to negative emissions. However, land-based bioenergy options need to be compatible with other biodiversity objectives of the European Union. They must take into account the issues of agricultural sustainability and food security. Since the models used in the present report do not fully characterize the nexus between energy and land-use, the present report does not include this technical option.

As for the CGE models, they only account for CO_2 emissions related to fossil fuel combustion Arguably, CO_2 emissions represent the main share of GHG. Nonetheless, this constitutes a limitation for evaluating mitigation scenarios. Yet this report's deep decarbonization scenarios focus mostly on the energy system.

Other caveats will be made in chapter 3 regarding the detailed modelling of energy generation in a general equilibrium framework, assumptions made on technical progress, and the representation of new technologies.

1.4 The Structure of Italy's Current Energy System and GHG Emissions Trends

Elaborating feasible deep decarbonization pathways requires taking into account the structural characteristics of the Italian energy system and the economy at large.

Historically, Italian total primary energy demand (gross inland consumption) shows an increasing trend until the peak year 2005, when oil prices in euros started to rise. Thereafter, demand declined, to a particularly pronounced degree during the years of deep economic crisis (2009-2013).

Italy is characterized by specific natural resources, geography, and socio-cultural and economic factors. Italy is surrounded by the Alps in the north and crossed longitudinally by the Apennine mountain chain: these orographic characteristics restrict the possibility of using railroads to move people and goods, both towards neighboring countries in the north and from the Tirrenian to the Adriatic coast (or vice-versa). This means that the country heavily relies on road and, secondarily, maritime transport. Moreover, the country is characterized by high seismicity along the Apennines, which host the biggest active volcanoes in Europe. The Italian energy mix has for many years been characterized by a dominant role of oil (until 2012) and large use of oil products for road transport, a higher share of gas and hydro than other European countries, and limited use of coal. Resource endowment includes small and very poor quality coal deposits, limited but nontrivial hydrocarbon resources on land and offshore, important hydro resources almost fully exploited, few areas with potential for offshore wind, and lots of sunshine in the South. Natural gas is the preferred fuel for power generation, residential heating, and industrial consumption because of the lack of cheap coal resources, the existence of some gas resources in the Po valley and the Adriatic, and long-term planning choices, made in the past, to build the necessary gas grid infrastructure. The country has limited high temperature geothermal resources in Tuscany that were exploited early, but cannot contribute much towards satisfying Italian energy demand.

Currently, 10-11% of gas is produced domestically. The remainder is imported, mainly through pipelines. In 2013, 45% of gas imports came from Russia, 20% from Algeria, 9% from Libya, and 8.6% from Qatar, with the rest

coming mostly from EU countries and Norway. Some nontrivial[13] oil resources can be found mostly in the Basilicata region: production covers about 9% of domestic needs.

Italy's nuclear program was mothballed after referenda in 1987 and 2011. The reasons included the perceived risk of nuclear technology in an earthquake-prone country, and the risk of pollution by nuclear waste. The outcome is an absence of nuclear power generation in the energy mix.

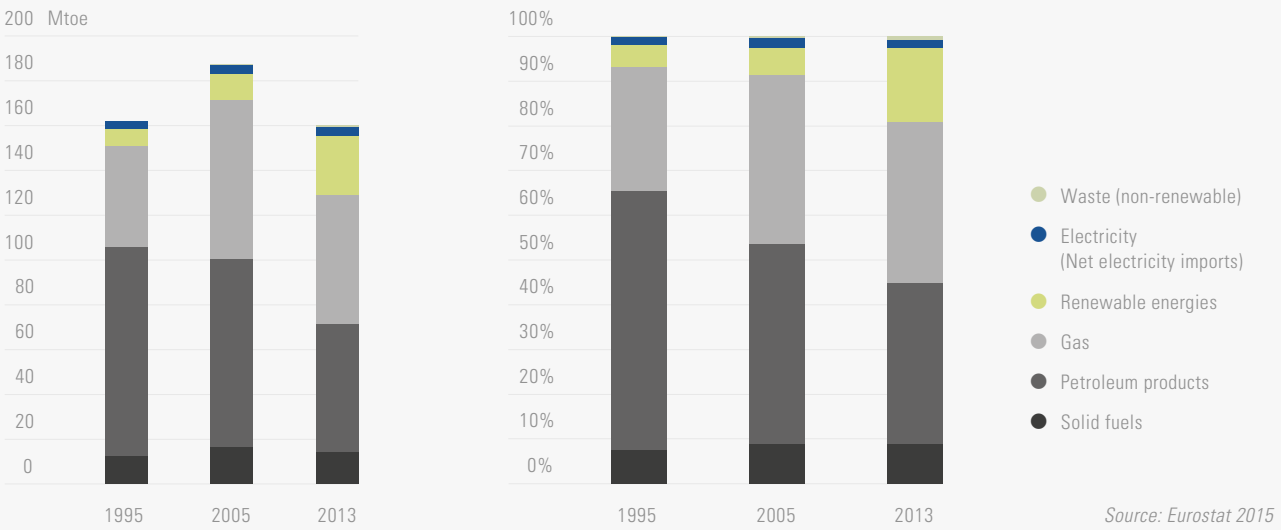
Over the period 1995-2013, the fuel mix showed a continuous decrease in consumption of oil and oil products, a steady increase in gas use (peaking in 2005), and the sustained growth of renewables. Over the same period, oil use in power generation was replaced by gas. More recently, gas has increasingly been losing market share to electric renewables. Oil use in transport is decreasing thanks to the fuel and emission standards introduced in EU countries, but since 2008 oil prices and the economic crisis have eroded households' purchasing power and incomes, and hit businesses' economic activity.

Gas has made substantial inroads in the residential and service sectors, but its use is limited by income effects in households and by efficiency measures. Moreover, gas is facing competition by thermal renewables or electricity.

The use of solid fuels, mainly coal in the iron and steel industries and in power generation, has remained remarkably constant in quantitative terms: without a change in industry structure, the use of coal use in primary iron and steel production is hard to replace. Furthermore, its survival in power generation is due to coal's relatively low price in recent years.

Gas reached the highest share in 2010. With the progressive decline of oil, in 2013, gas overtook oil and covered an equal share of Italy's total primary energy demand (Figure 2). For the sake of comparison, Figure 3 shows the shares of various energy inputs in primary energy in 2012 for the EU28 and Italy. The share covered by nuclear energy in the EU energy mix is supplied in Italy by gas for electricity generation. In the EU, the trend since 1990

Figure 2 – Total primary energy supply in Italy – Mtoe (left) and % shares (right), 1995, 2005, 2013



Source: Eurostat 2015

13 Italy has the second largest proven oil reserves in the EU-28, after the UK. See BP Statistical Review of World Energy 2014.

has been decreasing use of solid fuels and an increase in gas and renewables.

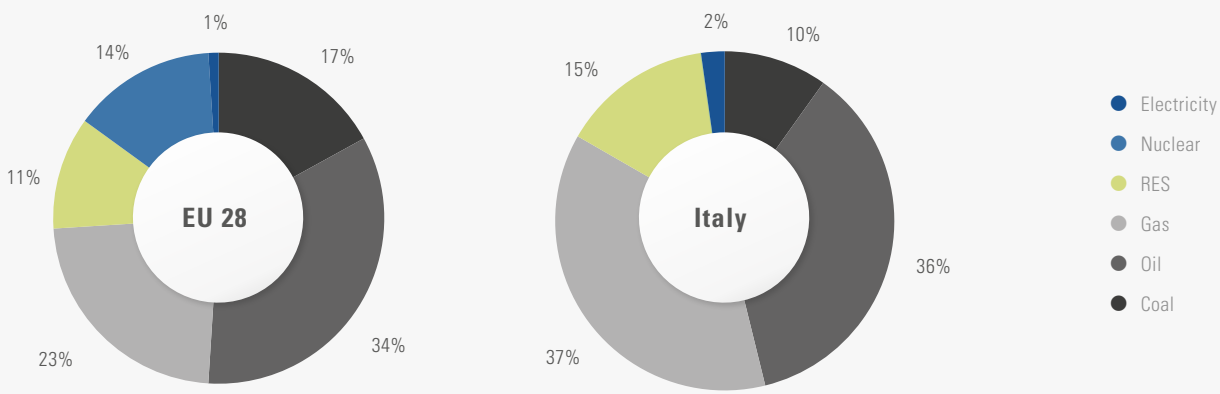
In Italy, gas is often seen as a transition fuel on the way to a low-carbon economy, but the trends above suggest that its role may be already waning. The erosion of its share of the mix, due to increased use of renewables and improved energy efficiency in power generation and in end use sectors is likely to continue. Whether or not gas will play a strong role in this transition hinges upon a strong recovery of the manufacturing sector, low gas prices, and a more significant penetration of gas in transport fostered by policy choice. Furthermore, gas-generation technologies may be used for base-load power of intermittent renewable energy sources (RES), until implementation of less-expensive storage systems.

The Italian reliance on imported fuels (particularly oil and gas, but also coal and electricity) has remained very high: above 80% until recently. By comparison, the EU28 has a rate of import dependency of about 53%.[14] Italy has one of the highest dependence rates in Europe, which causes concern when energy prices are high or in case of supply disruptions. During the last decade, Italy has tried to diversify its sources of energy, in an attempt to redress the excessive reliance on certain supplying countries for its energy, and to reduce the risks resulting from energy dependence. Plans are to be implemented to strengthen oil and gas exploration and production, both on land and offshore, the NES announced in 2013. This may lead to reductions in dependence in the medium term. This, however, is subject to a weakening of local opposition to new mining activities.

Signs of change have emerged in recent years: import dependence reached 87% in 2006, and then declined, falling to 77% in 2013. But this trend seems mostly related to the reduction in energy consumption and the increasing participation of renewables in the fuel mix.

To achieve the objectives defined in the Kyoto Protocol (in terms of CO_2 emissions) and to meet the ambitious targets of EU directive 2009/28/EC (a RES share of 17% in 2020 in gross final consumption) and of the recent NES (a RES share of 19-20%), Italy adopted several policy instruments. These included green certificates, feed-in tariffs, investment subsidies, and tax deductions.

Figure 3 – Fuel shares in total primary energy in EU 28 and Italy – years 2012



Source: Eurostat 2015

14 Eurostat, 2015

From 2005 on, electric power generation from renewable plants increased steadily. Major contributors have been new wind farms, bioenergy plants and, above all, photovoltaic plants which experienced a boom in 2011 (+275% increase in capacity compared to 2010). These developments, spurred by generous incentives, have generated considerable costs for the system in recent years, in particular in electricity bills. Figure 4 shows the evolution of renewable energy installed capacity over time.

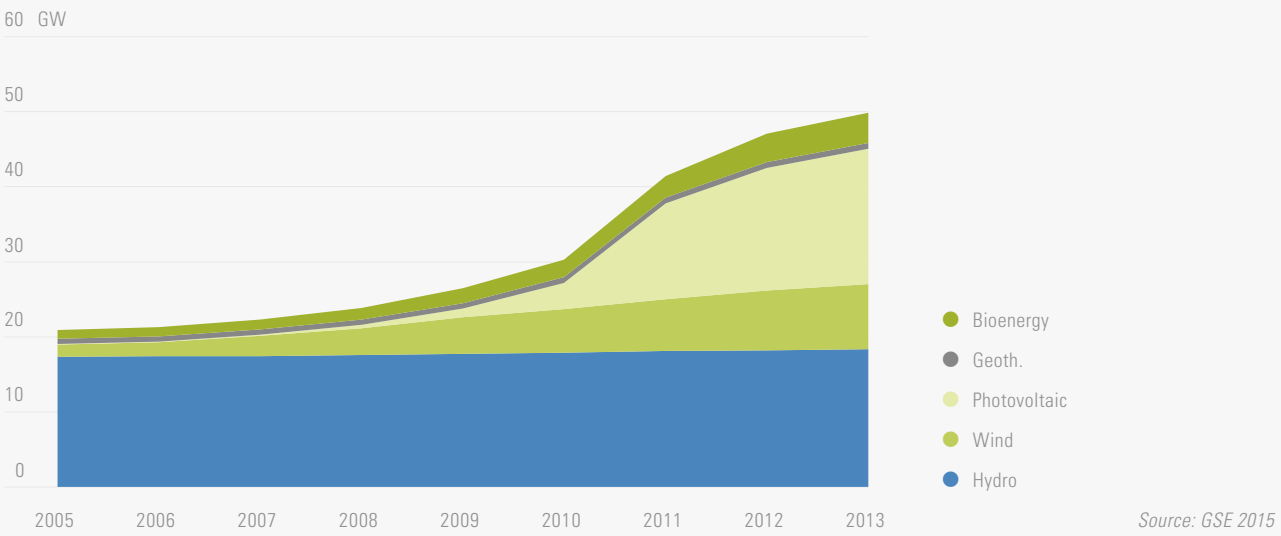
The recent economic crisis, followed by a drop in electricity consumption, has been borne entirely by traditional thermoelectric plants, which reduced output, since renewable sources benefit from the so-called 'dispatching priority' (i.e. guarantee of priority withdrawal by the network operator) which leaves less space in the grid for electricity generated by conventional power plants.

The Not-In-My-Back-Yard (NIMBY) factor in Italy hinders with equal strength both fossil-fuel based energy plants and infrastructure (like LNG regasification terminals or gas pipelines) and renewable ones (like offshore wind farms). If this is not addressed by national policies, it could block any energy transition strategy.

Italy has a large manufacturing sector, second only to Germany's in the EU. Therefore, the manufacturing's share of final energy consumption is quite important. However, like nearly all industrialized countries, Italy is experiencing a shift in the composition of total value-added, from manufacturing activities towards tertiary and service activities. This trend is mirrored by the relative shares in energy consumption and is expected to continue into the future.

Italy's tertiary sector has the highest energy consumption growth rate. Energy consumption in the residential sector grew slightly until 2013, both in absolute and relative terms, with the exception of the years 2007-2009. Energy consumption in the transport sector showed robust growth until 2007, led by the increase in freight and in personal incomes, but in recent years has been negatively affected by the economic crisis. The introduction of fuel efficiency and CO_2 emission standards in new cars has likely played a

Figure 4 – Installed capacity of renewable generation plants - 2005-2013

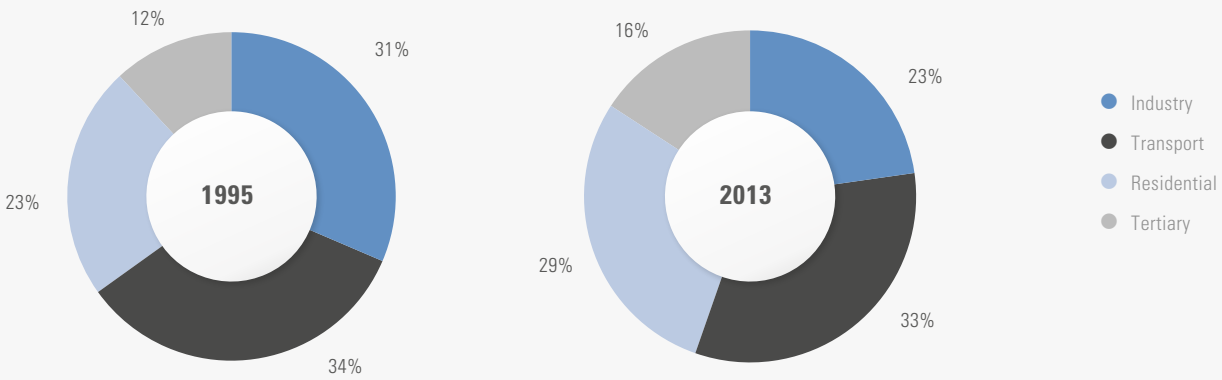


Source: GSE 2015

role in this decrease, and that role is expected to continue even in an economic recovery scenario. The sectoral shares of final energy consumption is shown in Figure 5 for the years 1995 and 2013. Due to the scarcity of domestic energy resources and high energy costs, the energy intensity of GDP in Italy has historically been lower than the European average. The oil price shocks of the 1970's and late-1980's forced the Italian energy system to become extremely efficient. However since 1990, energy intensity decreased rather sharply in other EU countries, while in Italy it remained rather stable until 2005 and decreased only slightly afterwards. It appears that the low energy prices prevailing from the 1990's until 2005 induced some complacency. Currently, Italian energy intensity is lower than the EU28 average.

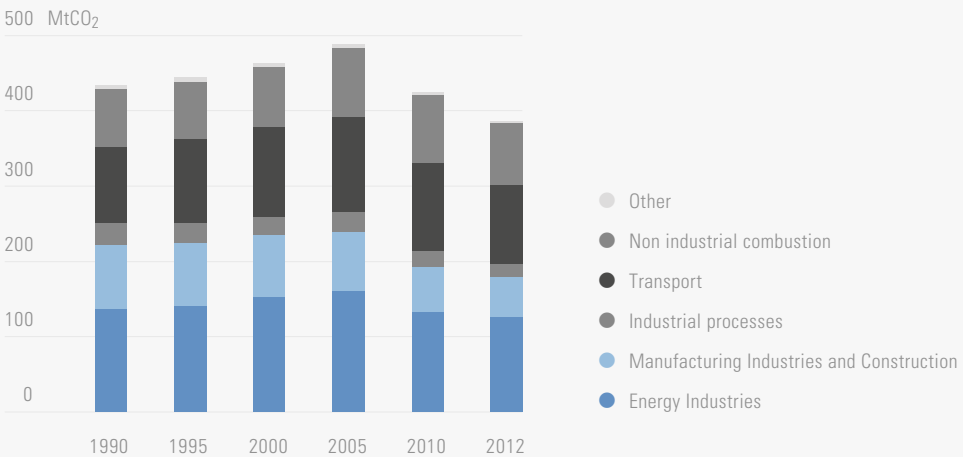
CO_2 accounts for 84% of total GHG emissions (in CO_2 eq) and closely reflects the evolution of the Italian economic structure and fuel mix.

Figure 5 – Final energy consumption by sectors in Italy



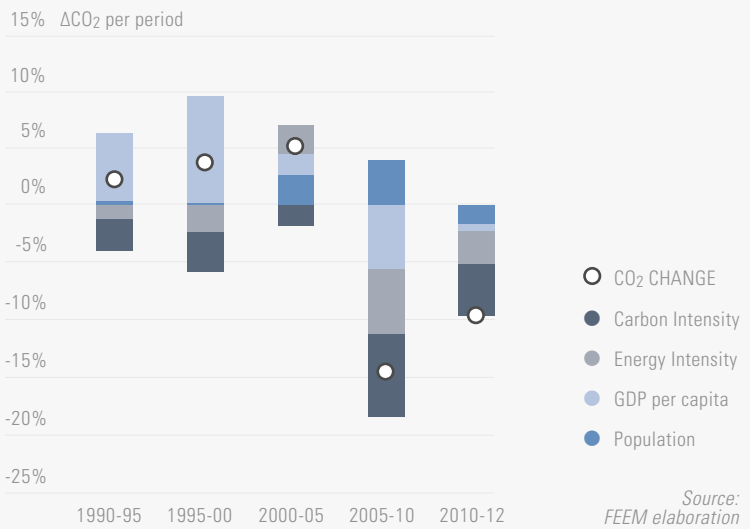
Source: Eurostat 2015

Figure 6 – CO2 emissions by sectors from 1990 to 2012



Source: EEA 2015

Figure 7 – decomposition of ΔCO_2 - RLD



Source: FEEM elaboration

Between 1990 and 2004, Italy recorded an increase in emissions due to the growth of the economy. In more recent years, the combined effect of the economic crisis and the higher share of renewables in the energy mix led to a notable reduction of carbon emissions (Figure 6).

CO_2 emissions decreased by 11% between 1990 (434.7 Mtons CO_2) and 2012 (386.7 Mtons). In the energy sector, combustion based CO_2 emissions in 2012 were 8.8% lower than in 1990. The largest share of CO_2 emissions in 2012 originated in the energy industries (32.5%) and transport sector (27.1%). Non-industrial combustion accounted for 21.2% and the manufacturing and construction industries for 13.9%. The remaining emissions came from industrial processes (4.4%) and other sectors (0.9%).

Figure 7 decomposes energy-related CO_2 emissions percentage changes in the sum of changes in GDP per capita, energy intensity, and carbon intensity, using a decomposition technique for five-year intervals.[15] The Figure shows that CO_2 emissions grew before 2005 and decreased afterwards. This indicates a decoupling between energy use and carbon emissions in recent years. In the period 2005-2010, the decrease is attributable to the erosion of GDP per capita, the decrease in energy intensity, and carbon intensity. More recently, in 2010-2012, the decrease in CO_2 emissions is attributable, for the most part, to lower carbon and energy intensity.

2 Deep Decarbonization Pathways

2.1 Challenges and Uncertainties for the Italian Energy System

The deep decarbonization of the Italian energy system can be achieved through multiple and alternative pathways. The illustrative pathways outlined in this exercise are based on the present structure of the Italian energy system, its characteristics, and current trends (discussed in Section 1). To identify these pathways requires considering not only the range of options available, but also the challenges and uncertainties about the availability of key technologies and resources, as well as policy, and socio-economic and cultural factors.

15 The decomposition methods used to perform the analysis is the Refined Laspeyres Decomposition Method (henceforth RLD). Population data are from the ISTAT. Gross Inland Consumption of Energy (GIC) and Gross Domestic Product (GDP in million euros chain linked volumes with 2010 as reference year) are from EUROSTAT. Total Carbon dioxide emissions from the consumption of energy were provided by EEA in million metric tons.

Some options do not appear viable at the present time for political reasons (nuclear power).[16] Other options' deployment will be limited by resource availability (greater use of domestic biomass, further development of large hydro, etc.). However, a range of possible options and strategies still exists to address the challenges of energy transition. There is some room for substitution among decarbonization options and technologies and the actual choices will take a more definite shape over time as we gain knowledge. The final transition path will depend on the availability of alternatives at the required scale (including the supporting infrastructure), and the corresponding costs.

The main pillars of a deep decarbonization strategy for Italy are already known, in part, from previous scenario analyses.[17] They are:

- Strong decarbonization of power generation.
- Increased electrification of heat production and transport.
- Greater energy efficiency.

These pillars can be translated into the following strategies:

- Fuel switching away from the most carbon-intensive fossil fuels and towards low- or zero-carbon energy sources in all sectors.
- Diffusion of renewables in power generation, as well as in heat uses (in particular, an increase in the use of biomass).
- Modal shift in the transport sector from private transport to collective public transport or car sharing, and from road transport of goods to rail and maritime.
- Across-the-board technological change, which requires R&D for innovation and the deployment and commercialization of advanced, low-carbon technologies, including in production processes).

Table 1 – Supply side challenges

	Challenges
No Nuclear	The nuclear option is not considered for political reasons (referendum in 2011). This could result in an increase in generation costs with greater use of other options.
RES	Intermittent renewables require suitable network infrastructure (smart grid, electric batteries and storage, etc ...) -> investment and management cost increases.
	Resource and technology availability
CCS	R&D and commercialization
	CO_2 storage sites and social acceptability

Source: ENEA

Implementing this strategy depends on realizing several conditions which, at this point in time, cannot be taken for granted. It can be argued that technologies are developed in a global market and depend only to some extent on Italian R&D. However, the rate at which innovation is adopted is arguably a country-level characteristic, which can be influenced by policy signals provided by the Italian government.

The construction of an energy pathway starts from a systematic analysis of its main drivers and the elements of uncertainty. Some of the most important uncertainties usually considered include the future evolution of population, economic growth, or the price of fossil fuel resources. The focus of the exercise for Italy, however, is not on these macroeconomic drivers, which for the time being will be taken as given. Rather, our focus is on the availability of technologies and resources, and on economic and social sources of uncertainty. A thorough analysis of the core uncertainties allows for identifying the main determinants of pathways, and the various scenarios are developed by postulating different assumptions, with respect to such key drivers. Below we identify and discuss the main technological, social, or resource-related uncertainties for Italy, which include both the supply and the demand side.

On the supply side the main challenges, discussed in Table 1, relate to:

16 See Chapter 1

17 *Virdis, Gaeta et al.(2014) Verso un'Italia low-carbon: sistema energetico, occupazione, investimenti. Rapporto Energia e Ambiente volume Scenari e Strategie. 2013 http://www.enea.it/it/produzione-scientifica/rapporto-energia-e-ambiente-1/rapporto-energia-e-ambiente-scenari-e-strategie-2013*

- the unavailability of the nuclear option in Italy;
- the possibility of greatly increasing the use of renewables in power generation;
- the commercial availability at reasonable cost of carbon capture and storage technologies (CCS).

Nuclear technology is commercially available, and tried and tested in several parts of Europe. Hence the uncertainty concerns its affordability (costs have been increasing recently) and most of all its social acceptability in Italy. Two referenda, held at different points in time, rejected this technology and resulted in the dismantling of plants that were operating. While the citizens' opinion on this technology may change in the future, for the time being the nuclear route has been barred.

This could increase generation costs due to the greater use of other options. The main options that remain for decarbonizing the power sector are increasing the share of production from renewable energy sources (many of which are intermittent), or achieving commercial availability, at a reasonable cost, of carbon capture and storage (CCS) technologies. Both of these are arguably more expensive than nuclear.

Renewables raise concerns. One is the issue of resources and technological improvement (e.g., the availability of windfarm sites with sufficient wind speeds both on land and offshore; suitable places to install solar PV farms or solar concentration plants, or to grow biomass for energy use; geothermal or hydraulic resources, etc.). There are also concerns with respect to social acceptability. We briefly discuss the most important issue for each of the key energy technologies considered.

Wind: In 2013, Italy had a total installed wind generation capacity equal to 8.6 GW, which produced 14.9TWh[18]. Offshore wind farms are still at the project stage and their deployment faces significant technical challenges. Although Italy has a very long coastline, it has very few sites with suitable average wind speeds (which are however not comparable to the superior wind conditions of northern European coasts) and the best sites are located relatively far from the coast. Given the steep profile of Italian coastal waters, which become rather deep even at short distances from the shore, this means that the sites with best wind resources are located in deep waters. Technology today can accommodate the building of a standard, fixed-bottom tower in water no more than 30-35 meters deep. In Italy this means only wind projects 5-10 km maximum from the shore are possible, a distance that would make the wind generators very obvious in the landscape, creating a visual disturbance and loss of aesthetic value. For this and other reasons, the offshore wind farm option is likely to raise significant problems of social acceptability. New concepts, such as floating wind turbines, are being developed and may solve this specific issue in the future. Provided that floating turbine technology can actually be adopted at reasonable cost, the potential for exploitable offshore wind could be much greater than the 12 TWh/year attainable with current technology[19].

Wind generation is also hindered by significant administrative barriers. As of 2015, only nine offshore wind project proposals presented to the Italian Ministry for the Environment, Land and Sea have passed the required Environmental

18 GSE: Rapporto Statistico: Energia da Fonti Rinnovabili, Anno 2013. (2015). Onshore generation potential for Italy is estimated by the EEA at 169TWh by 2020 and at 581TWh by 2030 for a cost of 6.7cents/kWh or below (European Environment Agency: Europe's onshore and offshore wind energy potential EEA Technical Report no 6/2009. ISSN 1725-2237)

19 See Gaudiosi G. and C. Borri: "Offshore wind energy in the Mediterranean countries". In *Revue des Energies Renouvelables SMEE'10 Bou Ismail Tipaza (2010) 173 – 188*

Impact Assessment (VIA – Valutazione Impatto Ambientale), though none are in production. Only one wind project, a 30 MW, near-shore wind park in Taranto in Puglia (2.9 km from shore) received a final "Autorizzazione Unica[20]" . The National Renewable Energy Action Plan (NREAP)[21] includes a target for offshore wind in Italy of 100 MW installed by 2013; this has not been reached and there are serious doubts about whether the target of 680 MW in 2020 will be achieved, as well.

Solar: Installed capacity of solar energy was 18 GW in 2013 (all from photovoltaics), with a production of 21.6TWh.[22] The exploitable potential is still large for rooftop applications, but for new ground PV plants, the competition with agricultural land is becoming a problem and is restricted by the provisions of the Ministerial Decree of 10 September 2010[23]. The Decree-Law 24 January 2012 forbids granting incentives to installations built on land devoted to agricultural purposes. As for concentrated solar power, the best sites for maximum intensity of incoming sunlight and suitable terrain would be limited to Southern Italy, where there are presently only three demonstration plants operating (ENEL-Priolo Gargallo, Falk-Rende, and ASE-Massa Martana). Hence, the most likely future for solar technologies will be distributed generation or heat production. That would increase the need to develop smart grids capable of handling this type of electricity production.

Bioenergy: Installed power capacity from bioenergy is presently about 4 GW, of which 1.6 GW is from solid biomass and the rest from biogas and bio-liquids. Power generated in 2013 amounted to about 17 TWh. Quantifying the available biomass is more complex. Several estimates exist for residual biomass; they vary depending on whether or not solid urban waste is included. ENAMA[24] estimates an annual potential of 13 Mtoe including agriculture, forestry, livestock, and other industrial residues including food and wood products but excluding the biomass part of urban waste. To these figures, one should add the value of energy crops, estimated in further 7-10 Mtep, but competition with agricultural land could become a problem if this grows. All together, these bioenergy resources should add up to around 20 Mtep, which could be increased with the adoption of appropriate production technologies.

For renewables, improvements in technology (for instance, increasing the transformation efficiency of PV, or more fully exploiting available wind) may release to some extent the constraint posed by limited physical resources. However, social acceptability issues remain, and are likely to become more serious with increased use of land and offshore resources for energy production, and the loss of landscape value as highlighted by recent stronger grassroots opposition to wind farms (both on land and offshore) and solar farms.

For non-dispatchable renewables such as wind and solar, the variability in power generation poses an additional source of uncertainty. There is a need to ensure the stability of the grid and the reliability of the power supply. This requires solving technological challenges (such as development of technically viable storage systems) and economic ones (the cost to invest in storage systems, strengthen the power grid, and making it more resilient). Furthermore, non-dispatchable

20 The "Autorizzazione Unica" o "Single Authorization" is the "one-stop shop" authorization process to grant the right to construct and operate a (power) plant.

21 The EU Directive 2009/28/EC set national targets for the share of RES on gross final energy consumption, but required member countries to prepare and periodically revise NREAPs as a roadmap for the implementation of the targets

22 GSE 2015

23 "Guidelines for authorization of plants fueled by renewable sources"

24 ENAMA, National Agency for Agricultural Mechanization, Biomass Project 2011

energy sources are likely to require significant back-up capacity to meet peak demand, which will likely be under-utilized for most of its lifetime. This further increases the capital costs of the energy transformation.

CCS: The uncertainties surrounding CCS concern the cost of the carbon capture processes, and whether or not suitable storage sites can be found in the proximity of CO_2-emitting plants. The costs may vary significantly depending on the characteristics and concentration of the flue-gas streams. So the uncertainties are both technological and those of resource endowment. The Italian government has implemented the European Directive 2009/31/CE on CO_2 emissions storage in 2011 with the Decree Law n.162, identifying specific sites that are particularly suitable for storage. It has also promoted a few pilot projects that could provide relevant information for implementing CCS on a large scale. At present, of the three projects initially planned (ENEL-Porto Tolle, ENEL-Brindisi, and Sotacarbo-Sulcis), only the last remains active thanks to grants from the Region of Sardinia and the Ministry of Economic Development in the framework of the RD&D activities of the Sulcis Coal Technological Centre on capture and storage.[25] The first two were recently abandoned after a few months of operation.

Several technologies for carbon capture and separation are being tested, but at present, the carbon has to be trucked to the storage site. Storage capacity potential is estimated to be around 20-40 Gt CO_2 [26] (about 100-200 times the amount of current annual emissions from the thermoelectric sector), partly in aquifers and partly in exhausted oil and gas wells. But perhaps the greatest uncertainty lies in local populations' attitudes towards CCS technology around the storage sites. The length of time needed for authorization procedures is another big question.

On the demand side, the challenges, discussed in Table 2, relate to:

- the electrification of energy end users, in sectors including transport;
- the switch from fossil fuels to RES;
- the modal shift from private passenger transport to public transport;
- increasing energy efficiency both in buildings and in transport;

Table 2 – Demand side Challenges

	Challenges
Electrification	The non-availability of one or more decarbonization options in the power sector reduces the extent of electrification in the end-use sectors.
	Deployment of EV* and heat pumps.
RES in end-use sectors	Resource availability.
	Air quality (for biomass).
Transport	Infrastructure costs for modal shift and consumers' attitude towards public transport.
	R&D and costs of hydrogen and electrical storage.
Energy efficiency	High cost of retrofitting buildings and whether availability of financial resources.
Industry	CCS R&D and commercialization
	CO_2 storage sites and social acceptability
	High energy prices could influence the shift towards less energy-intensive industries

Source: ENEA ** Electrical vehicles*

25 See the Thematic Research Summary G. Girardi and E. Loria "Fossil Fuels with CCS" in the framework of the ERKC Project, 2014. https://setis.ec.europa.eu/energy-research/publications/fossil-fuels-ccs

26 CESI Ricerche (2010), Quattrocchi INGV (2007)

- the use of CCS technology in industrial processes whenever conditions are suitable.

But here, too, uncertainties exist about overcoming several critical obstacles.

The main uncertainties considered on the supply side also affect the demand side: limited availability of renewable resources (like biomass), lack of technology or its complexity, low social acceptability have a direct and an indirect effect via costs. Together, these uncertainties immediately translate into higher technology or infrastructure costs, which operate as a drag, slowing the penetration of low-carbon technologies and energy sources in Italy.

Electrification of end-uses may be discouraged by high electricity prices, if high prices prevail as a result of limited (or costly) low-carbon power generation. The electrification of transport faces a slightly different set of obstacles: It may be hindered, or at least delayed, if the cost of batteries does not decrease fast enough, or if batteries' lifetime, power density, and safety does not improve significantly. The lack of a sufficiently diffused recharging infrastructure would delay the broad adoption of electric cars. In the buildings sector, the penetration of electric heat pumps or appliances may be discouraged by capital costs, if households lack access to credit.

Further penetration of renewables in end-uses could be at risk because the resources (geothermal heat, biomass) are not available and because of environmental impacts (like air quality problems arising from the direct burning of biomass in traditional fireplaces and stoves).

In the transport sector, an enabling condition for decarbonization is electric or hydrogen storage that is both available and cost-competitive. The creation of a cost-competitive public transport infrastructure is another requisite for a modal shift. Consumer attitudes and preferences towards public transport would also a play a role.

In the residential sector, the cost of retrofitting and insulation, coupled with the lack of financial wherewithal by homeowners, represents a big hurdle to improving energy efficiency, even if the potential is very large. Yet another concern is the uncertainty about whether the necessary public policies, financing schemes, or appropriate market arrangements would continue. These would be necessary to facilitate investments in residential building efficiency.

Finally, in industry, especially energy-intensive ones, the question is whether commercial-scale CCS would be available. That could make the difference between maintaining a viable manufacturing sector in intermediate goods or losing big parts of it. Availability implies a reasonably cost-competitive capture technology, suitable storage sites and transport infrastructure, and solutions that can overcome public resistance so that CSS becomes socially acceptable.

2.2 Scenario Definition

In this sub-section, we present alternative options and strategies that reflect the challenges and uncertainties discussed above: the availability of key technologies and resources, policies, and socio-economic and cultural factors.

In view of the uncertainties and challenges characterizing the Italian energy system, multiple scenarios can help identify robust options for deep decarbonization. Three illustrative pathways towards an 80% emissions reduction by 2050 (compared to 1990 levels) were developed for this analysis and compared to a reference case.

These pathways differ in their assumptions about the critical uncertainties discussed above (such as the availability of CCS and renewables, social acceptability, and sectoral and technological discount rates). The three scenarios, summarized in Table 4, are defined as follows:

1. **The CCS + Renewables scenario (CCS)** envisions powering the energy system with a large share of electricity from renewables and with fossil fuel technologies, coupled with

CCS. A high rate of diffusion is assumed for such technologies; for this to be possible, public acceptance of key low-carbon generation technologies is implicit. The scenario envisions abundant renewable sources, capture technology, and CO_2 storage sites. These allow for the deep decarbonization of the electricity system, and lead to a high level of electrification of heating and transport services;

2. **The Energy Efficiency scenario (EFF) assumes** fewer options are available to decarbonize the electricity system, resulting in relatively higher costs and a reduction of the electricity consumed by end-use sectors. To achieve the target emission level, this scenario envisions an increased reliance on advanced energy-efficiency technologies, and greater use of renewable energy for heat and transportation. The policy factor, and the individual preference factors that influence household and industry investment are represented through a lower sectoral discount rate, which stimulates the higher penetration of new and advanced energy-efficient technologies.
3. **The Demand Reduction scenario (DMD_RED)** models the response of the energy system to a limited availability/commercialization of CCS (especially in the industrial sector) and a high cost of decarbonization. Public acceptance of CCS in this scenario is low, in part due to delayed development and insufficient policy support. This low-carbon scenario is simulated using the TIMES-Italy model version with price elastic demand: the demand drivers of end-use sectors in this case are influenced by the high fuel and energy carrier prices.

All the scenarios are implemented with the TIMES-Italy model using the same technological parameters and developments, macroeconomic drivers (population, GDP growth, fuel prices projections) and emission abatement level. The exogenous assumptions on GDP and value added are based on DG ECFIN projections and the GEM-E3 model results of the European Commission[27] (Table 3).

These economic projections assume an average annual growth of 1.18% in the near term (2030) and 1.31% in the long term (2050), with the structure of the economy remaining rather stable in the period considered. Based on ISTAT[28] projections, population is expected to increase 5.3% by 2050. In the decarbonization scenarios, a 15% modal shift is assumed from private transport towards collective mobility. A smaller shift is assumed for road-to-rail or sea transport of goods, compared to the reference scenario.

Before analyzing the possible deep decarbon-

Table 3 – Projections of Socio-economic Drivers

	2010	2020	2030	2040	2050
GDP (2010-B€)	1553	1691	1964	2225	2547
Population (thousands)	60340	62877	64491	65694	65915

Sources: EC and ISTAT

Table 4 – Three scenarios and rationales

		CCS	EFF	DMD_RED
Generation				
	Nuclear	-	-	-
	RES	+++	++	++
	CCS	+++	++	+
Electrification				
	Heat pumps, EV and PHEV	+++	++	++
	Fuel switch to electricity	+++	+	+
End-use sectors				
	Building retrofit	++	+++	+++
	Advanced eff. technologies	++	+++	+++
	RES for heat and transportation	+++	+++	++
	Fuel switch in final sectors	++	+++	+++
	CCS in Industrial sector	+++	++	+
Service demand in final sectors				
	Transport modal shift	+	+	++
	Reduction in Industry output	-	-	++

Source: ENEA

27 EU energy, transport and GHG emissions TREND To 2050, Reference scenario 2013 – E3M-Lab for European Commission

28 Italian National Institute for Statistics - http://www.istat.it/en/files/2015/03/03-population.pdf

ization pathways, a **Reference scenario (REF)** for Italy has been developed, to be used for the analysis. The REF is consistent with the European Commission's[29] 2013 PRIMES scenario. The REF reflects current trends in macroeconomics drivers, the present trends of development of the Italian energy system and of energy supply and demand. It includes all binding targets currently set in Italian and EU legislation regarding renewable energy and reductions of GHG emissions, as well as legislation promoting energy efficiency. The Emission Trading Scheme (ETS) Directive[30] continues to influence the energy system in accordance to an "emission allowances" cap having to decrease linearly at a yearly rate of 1.74%. Hence, the Reference scenario used in this analysis is an ambitious scenario which, to realize, would require significant changes in policy and technologies, compared with a business-as-usual projection. All three deep decarbonization scenarios are illustrated and compared to the REF, and to historical energy data for the key variables.

2.3 Results and Comparisons

This analysis assesses the engineering and economic feasibility of three alternative deep decarbonization pathways for the Italian energy system.

Given the expected impacts of current European and Italian policies, and the lingering effects of the recent economic crisis, Italy could achieve, and likely even exceed, Energy and Climate Package emission targets to 2020[31] in the Reference Scenario. In the Reference Scenario, the combined impact of current policies is the lowering of the energy-intensity economic activities, together with a decrease in the carbon intensity of energy demand. Under these conditions, CO_2 emissions decrease until 2050. In 2020 they fall to 377 Mtons of CO_2 (-22% vs 2005), while in 2050 they do not exceed 320 Mtons (-25% vs 2010), entailing a -28.5% reduction in per capita emissions (from 7.0 to 5.0 tCO_2 per person) between 2010 and 2050.

However, the evolution under the Reference Scenario does not ensure that Italy will achieve a future sustainable energy system, nor deep decarbonization (-80% compared to 1990 levels), as recommended in the European Communication COM (2011) 112.[32] A stronger effort to develop technology, and more focused policy planning are needed to support the deep decarbonization of the Italian energy system. For this reason, the three DDP Scenarios identify key mitigation areas, and alternative options, with respect to the Reference Scenario.

To reduce domestic emissions by at least 40% in 2030 and 80% in 2050 (compared to 1990), a smooth and efficient transition is assumed. All three DDPs achieve energy and process emissions below 90 $MtCO_2$, or 1.5 tCO_2 per person (Figure 8).

Emissions reductions in all three DDPs analyzed are driven by a drastic decrease in the carbon intensity of energy, as renewables and biomass become the dominant energy sources. The most important driver, however, is an almost total decarbonization of power generation processes. This sector achieves a 96% decrease in emissions in 2050 compared to 2010, and an absolute reduction, compared to the Reference Scenario, of at least of 50 Mt CO_2). In fact, the assumption of continuously decreasing European Union ETS

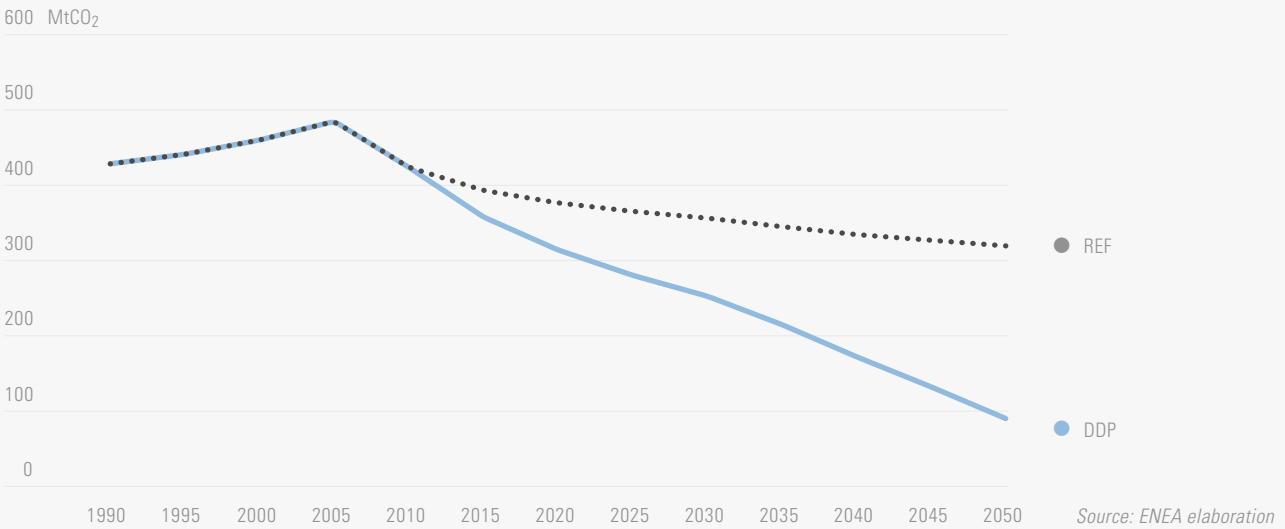
29 EU energy, transport and GHG emissions "TREND TO 2050, Reference scenario 2013" – E3M-Lab for European Commission

30 Emission Trading System – Directive 2003/87/EC, establishing a scheme for greenhouse gas emission allowances trading within the Community

31 See the Impact Assessment to the Communication "A policy framework for climate and energy in the period from 2020 up to 2030", (SWD(2014)15 final)

32 European Communication COM (2011) 112 Roadmap for moving to a low carbon economy in 2050

Figure 8 – Energy-related and process CO2 emissions in Reference Scenario and Deep Decarbonization pathways



Source: ENEA elaboration

emission allowances mentioned above already drives strong carbon reductions in the Reference Scenario up to 2050, particularly in the power generation sector. This effect is obviously more pronounced in the Deep Decarbonization Pathways (DDPs) due to a tighter constraint in total emissions, and the use of renewable sources and CO_2 capture and storage (CCS).

At the same time, the efficiency of end-use technologies is crucial to achieve the 2050 target in all the DDPs considered. The residential and services sectors can reduce CO_2 emissions by as much as 90-95% compared to 2010, depending on the DDP considered. This arises from the combination of increased energy efficiency, building retrofitting, and switching from fossil fuels to electricity and renewable energy. Energy efficiency and electrification are two key pillars of the industrial decarbonization (50-55% less industrial emissions than 2010 levels and 33-36 Mt CO_2 less than in the Reference Scenario), but the availability of CO_2 capture and storage (CSS) is a crucial factor for reaching strict targets. The transport sector could avoid between 65-76 Mtons of CO_2 compared to the 2050 Reference level (65-73% less than 2010 level) by using electrical and hybrid vehicles, alternative and eco-sustainable fuels and modal shift towards collective mobility.

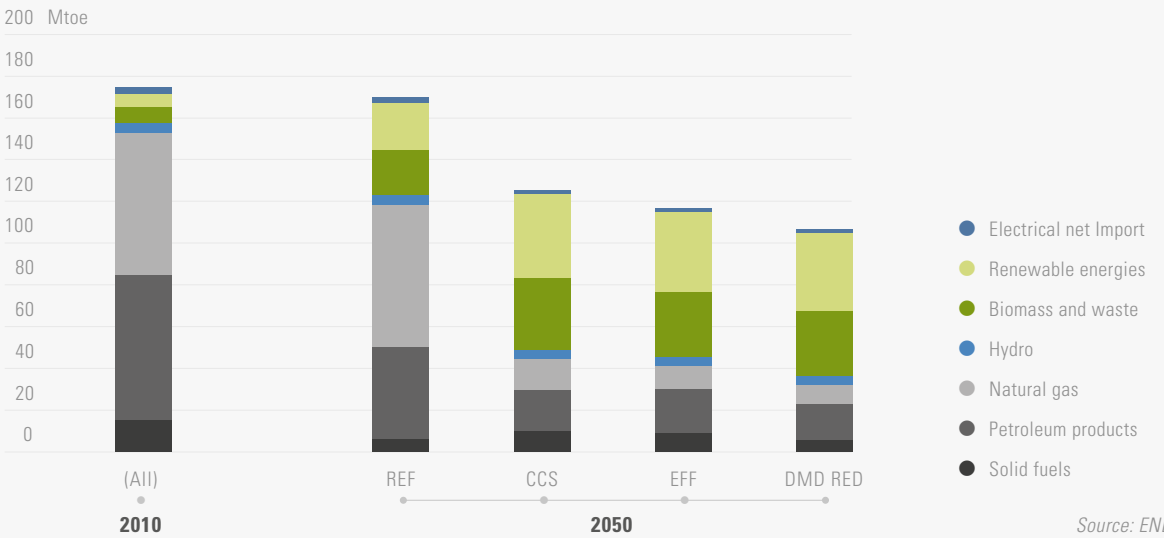
2.3.1 Total Primary Energy Supply

Energy emissions in the different scenarios reflect the different fuel mixes, and the technology options used to produce and consume energy, but the need to drastically reduce emissions leads inevitably to a decrease in the Italian primary energy supply (Figure 9). Decarbonizing the Italian economy and energy system will require a balanced combination of carbon and energy intensity improvements. The three DDPs analyzed result in different combinations of key elements of decarbonization: energy efficiency, renewable energy, carbon capture and storage, infrastructure, and power system evolution. The different mixes of technology and resources in the three DDP scenarios meet the decarbonization targets with varying costs, and varying asset and supply-chain implications.

In all DDPs, primary energy demand continuously decreases until 2050, to achieve at least a 28% reduction (compared to 2010) in the CCS scenario; and up to a 39% reduction in the DMD_RED Scenario, with an average annual rate ranging between -0.8% and -1.2%.

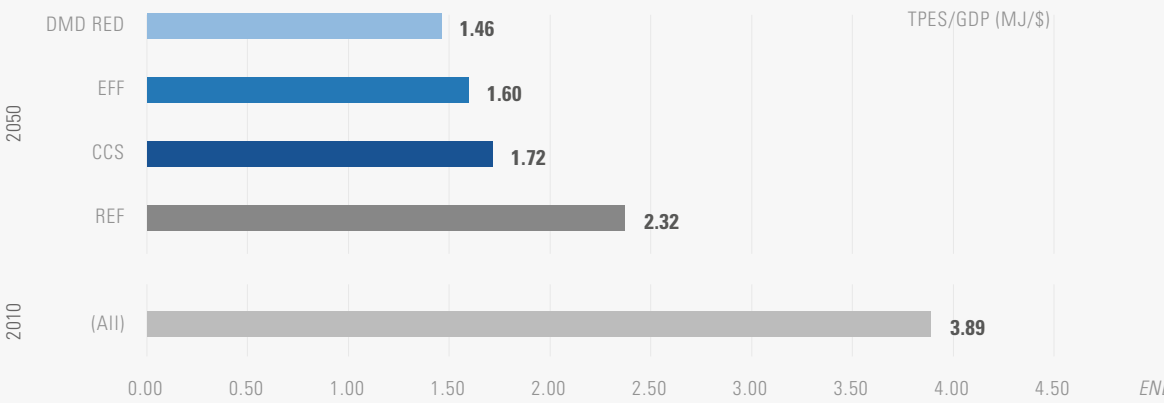
The contraction in primary energy demand is not due to reduced GDP or lower levels of sectoral economic activity (which remain the same in all scenarios except for the DMD_RED Scenario where activity is affected by energy price increase). Instead, the demand contracts mainly as a result of technological changes, and fuel shift on the demand and supply side. Energy efficiency is one of the main drivers of decarbonization in each scenario, as illustrated by energy intensities (Figure 10). Under the Reference Scenario, high energy efficiency improvements more than offset the

Figure 9 – Total Primary Energy Supply by energy source in three scenarios



Source: ENEA elaboration

Figure 10 – Energy intensity of GDP – MJ/$ 2005



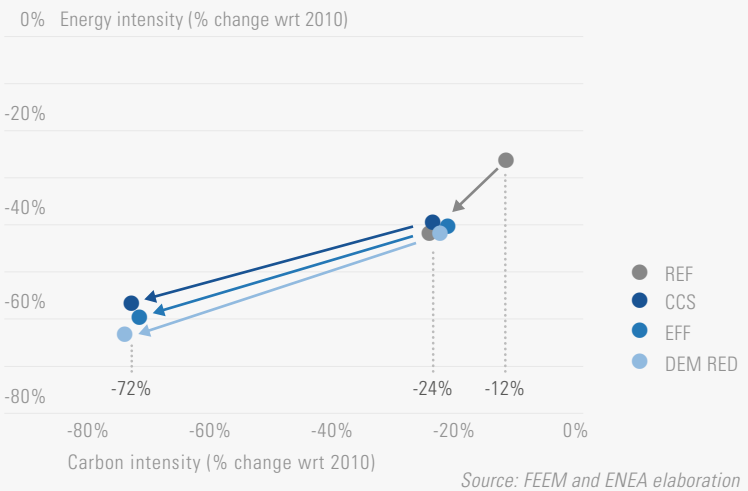
Source: ENEA elaboration

increase in consumption driven by economic growth (projected at the average annual rate of 1.24% from 2010 to 2050). This results in a declining energy intensity of GDP from 3.89 MJ/$ in 2010 to 2.32 MJ/$ by 2050 (-40%). However, to meet the Deep Decarbonization Pathway (DDP) targets, an even faster decrease in energy intensity is needed: about 2%-2.4% annually (1.46-1.72 MJ/$). The additional effort required to achieve that is, indeed, very challenging compared with recent historical performance: the decrease in energy intensity from 2000 to 2010 in Italy was rather slow: only -0.3% annually. Only in the last five years have significantly higher rates been reported (-1.1%). The economic crisis, which caused a contraction in primary consumption, and the effect of energy-efficiency policies, have contributed to accelerating the downward trend. In the future some buildings could even produce more energy than they consume with the installation and use of photovoltaic panels, solar thermal, and geothermal energy. Substituting RES for fossil fuels in power generation further reduces primary energy supply, for the same final energy service, lowering energy intensity, since conventionally many RES have an efficiency factor of 100%. In the DMD_RED Scenario, the energy intensity of GDP is low. This is due to increased energy efficiency and also to a reduction in industrial activity levels, and lower energy-intensity lifestyles (represented in this scenario by a more rational use of energy, or changes in energy services demand in response to higher energy prices.

Figure 11 characterizes the three DDPs in terms of variations in primary energy mix (carbon intensity, x-axis) and improvements in the aggregate energy intensity of GDP (energy intensity, y-axis) in the medium term (2030) and the long term (2050). Arrows illustrate the direction of change between 2030 and 2050. In the medium term, any decarbonizing strategy will need to rely slightly more on energy efficiency improvements. By 2050, the rate of reduction in carbon intensity will outpace efficiency improvements. The carbon intensity could decrease at approximately 3.0 - 3.2% average annual rate (a.a.r.) instead of the 0.7% a.a.r. in the Reference Scenario. As for energy intensity, this rate of decrease is much higher compared to what can be seen in recent historical trends: in the period 2000-2010, the carbon intensity has decreased at a 1.1% a.a.r..

Figure 11 shows the different scenarios follow very close trajectories, but in very different ways. In all DDPs, renewable sources progressively replace fossil fuel consumption (fossil fuels represent 30-35% of total consumption in 2050) and improvements in energy efficiency reduce the demand for them. Passenger and freight transportation continue to use petroleum products for long distances, but their use is significantly smaller (50% less than in the Reference Scenario, and 70-75% less than in 2010). Their decline is dramatic in the last years of the scenario projection when oil in transport is replaced by biofuels and electric vehicles.

Figure 11 – Energy and carbon intensity in DDPs from 2030 to 2050



Source: FEEM and ENEA elaboration

In the Reference Scenario, natural gas consumption is quite stable in the long term, meeting 40% of primary energy demand in 2050 despite the competition with renewable sources. The evolution of this energy commodity takes a very different track in all the DDP (from 39% of total primary energy supply (TPES) in 2010 to 9-11% in 2050). Even in power generation its role remains a small one, mostly in association with CCS.

The faster or slower development of CCS determines the role of solid fuels (coal) in the long term: CCS diffusion allows higher coal consumption in 2050, compared to the Reference Scenario. In the REF, coal use is still bound by the Emission Trading Scheme (ETS). Solid fuel consumption (14.9 Mtoe in 2010) is about 10 Mtoe in CCS, 9 Mtoe in EFF, and decreases until 5.3 Mtoe in DMD_RED. In the CCS scenario, consumption of fossil fuels, coal in particular, is slightly higher than in the EFF scenario, due to the high CCS technology availability and deployment (both in the electrical sector and in industry). The coal share in TPES (9% in 2010) varies between 8% in the CCS Scenario and 5% in DMD_RED.

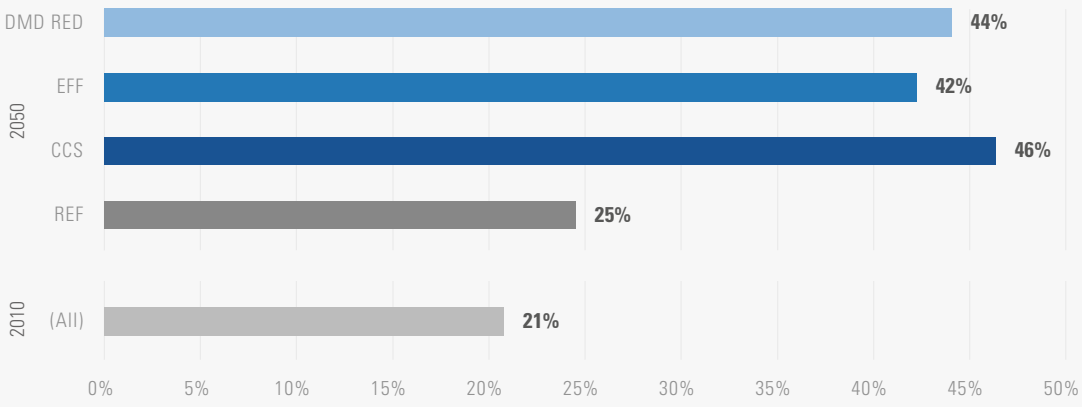
In the (DDP) Scenarios, energy efficiency, electrification, and fuel-shifting all reduce fossil fuel consumption. This results in significant source diversification and energy security. Compared to 2006, when Italian import dependence reached 87%, in 2050 it may drop to between 30%-35%. Furthermore, the DDPs translate into significantly lower Italian emissions per capita, from about 6.7 tons of CO_2 in 2010 to just under 1.5 tons per capita in 2050.

2.3.2 Generation Sector

The almost-complete decarbonization of the power sector is a pillar of the DDPs. According to the European Roadmap, the power sector could reduce emissions by 96-98% by 2050, despite high electrification in end-use sectors that in principle is expected to drive an increase of total production.

Under all the DDP scenarios, electricity demand grows compared to 2010 levels as a result of the greater penetration of electric appliances, heating, and propulsion systems (Figure 12). The increased use of electric devices is partly compensated by the appliances' greater energy efficiency as well as the increased thermal integrity of buildings in the residential and service sectors, and more rational use of energy everywhere. But overall, the effect of emerging new electricity uses on a large

Figure 12 – Electrification of final consumption



Source: ENEA elaboration

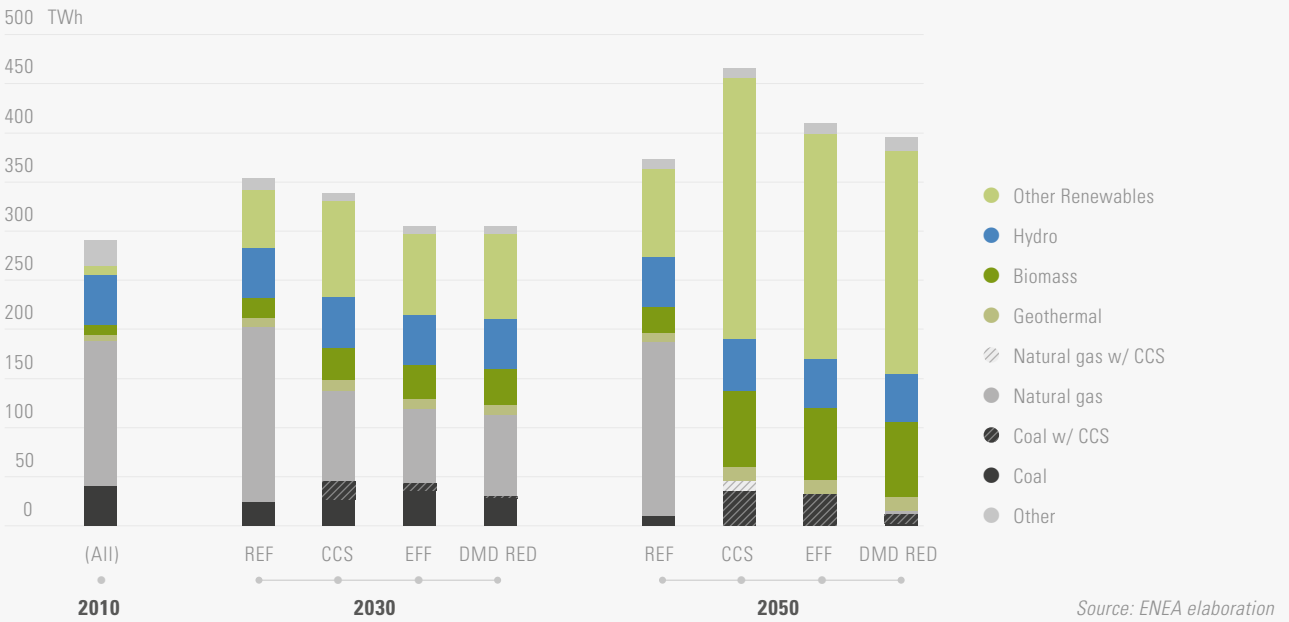
scale, for heating and transport, is decisive in lifting demand. The trajectory of this greater electricity consumption varies between sectors. The CCS Scenario reflects a higher penetration of CCS, wind, and solar in power generation and a higher electrification of heating and passenger transport. This scenario is characterized by high electricity consumption, 440 TWh in 2050, while the EFF Scenario reaches only 385 and the DMD_RED Scenario reaches 370 TWh in 2050.

The wide availability of renewables and CCS in the power sector allows a higher reliance on electricity. Scenarios with less accessible low-carbon electricity require more advanced technologies and other systems to reduce energy demand (such as building retrofits).

The reduction of emissions is simultaneous with the diversification of energy sources. Even in the Reference Scenario, the structure of power generation changes substantially compared to current levels, moving electricity production further towards natural gas and renewable sources. In Italy, the feed-in tariff scheme supporting RES has triggered a bigger-than-expected deployment of renewables, especially solar PV, until 2012.[33] RES output is set to continue growing until 2050, reaching 177 TWh, thanks to learning curve effects. In all the DDP Scenarios analyzed, RES provide a high and growing share of power generation (up to 93% in 2050). The contribution of variable RES (mainly solar and wind, on-shore and off-shore) expands more rapidly after 2030. Variable RES account for 55-58% of total net generation in 2050. While the RES share is very high and very similar in all the DDP scenarios, the amount of electricity generation from RES is not the same: in CCS it is about 410 TWh; in EFF it is 375 TWh, and in DMD_RED 370 TWh is generated from RES.

By 2050, the CCS Scenario has the greatest expansion of electricity, in particular from RES

Figure 13 – Electricity production in all scenario in 2030 and 2050



Source: ENEA elaboration

33 The FIT scheme for solar PV has ended in 2012 with the adoption of the last Conto Energia, and this has produced a halt in new PV projects.

(with a share of net electricity generation reaching 88%). In this Scenario, the wide availability of RES electricity and a large deployment of CCS allow increased electricity demand.

Solar plants provide the largest RES contribution, supplying 18% of net electricity generation in 2030 and rising to 28-31% in 2050 in DMD_RED and CCS Scenarios. Solar PV production amounts to 110 TWh in the CCS Scenario, 93 TWh in the EFF Scenario and 82 TWh in the DMD_RED Scenario. Concentrated Solar Power (CSP) with thermal storage provides an important contribution to solar generation: up to 37 TWh in the CCS Scenario, and at a minimum, 32 TWh in the EFF Scenario. This technology allows electricity production to extend up to about six hours after sunset. Wind plants provide 9-11% of total net generation in 2030, and increase to 25-28% in 2050. In all three DDPs, generation from offshore wind is also very important: up to 71 TWh in the CCS Scenario can be delivered by off-shore plants. In the EFF scenario, off-shore wind contribution is 60 TWh in 2050.

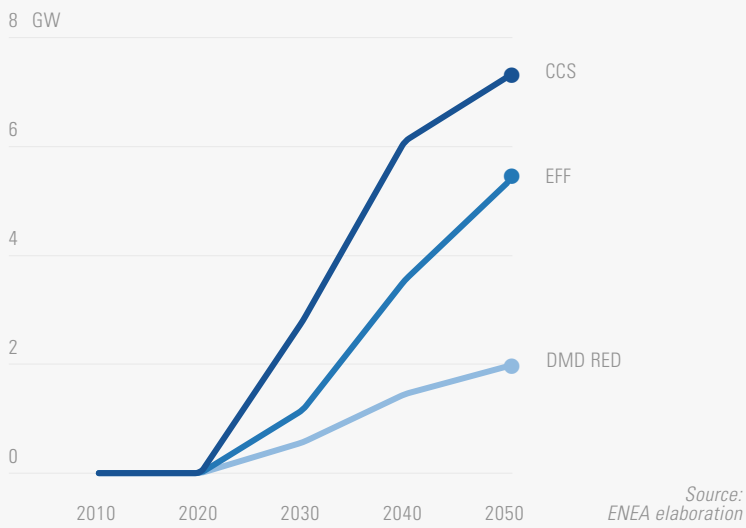
Hydro-power generation remains rather constant at 50-54 TWh, with an increase in small hydro. Production from pumped-hydro plants (used as a form of storage) rises from 3.3 TWh in 2010 to 9.5 TWh in 2050 in the CCS Scenario while in the DMD_RED Scenario it increases to 13 TWh.

The variability of RES can create problems of adequacy and reliability for traditional transmission grid in all DDPs; major investments will therefore be necessary for development of Smart Grids, storage systems (batteries, pumped-storage hydro and others), hydrogen production, and also for power reserve capacities. Self-production could then have a great diffusion across end-use sectors, especially in industry but also in the residential and service sectors. Bioenergy and waste technologies could have an increase in production over the next 40 years, up to at least 7 times the current level, especially in district heating and cogeneration plants.

Generation from conventional thermal plants declines significantly throughout the projection period, in particular in the last two decades. In the Reference Scenario, the phasing out of generation from solid fuels is very intensive because CCS technology is not available and the ETS CO_2 allowance price is assumed to increases considerably. When available, CCS technologies contribute significantly to mitigation in the DDPs (Figure 14). By 2050, about 84% of residual power sector emissions are captured in the CCS Scenario, about 25 $MtCO_2$ from coal and natural gas generation. In the EFF and DMD_RED Scenarios, only coal plants are equipped with CCS which captures 20 and respectively 6 Mtons of CO_2 emissions in 2050. By 2050, fossil fuels (natural gas and coal) are used only in the presence of CCS, except for the DMD_RED Scenario where a small amount of electricity is produced from gas plants without CCS (3 TWh) operating as peak load.

The DDPs radically change the structure of power generation. Generation capacity from fossil fuels in 2050 is affected by the availability of CCS technology, and is limited by cost-effective storage

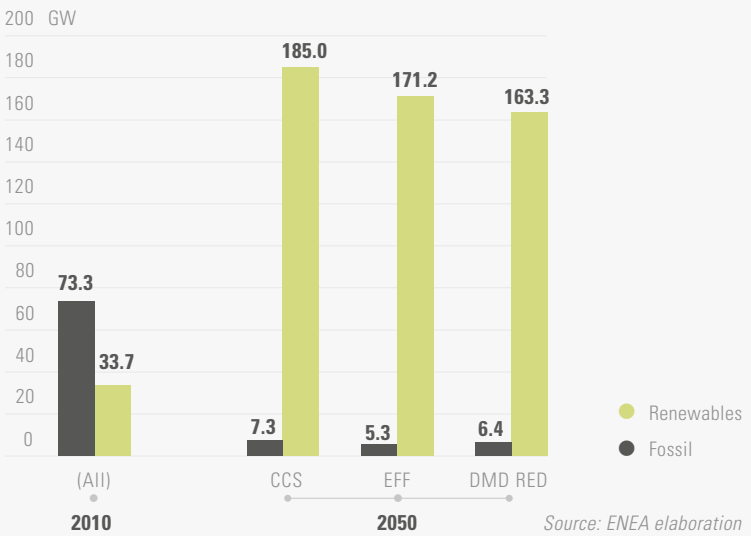
Figure 14 – CCS power capacity by scenario



Source: ENEA elaboration

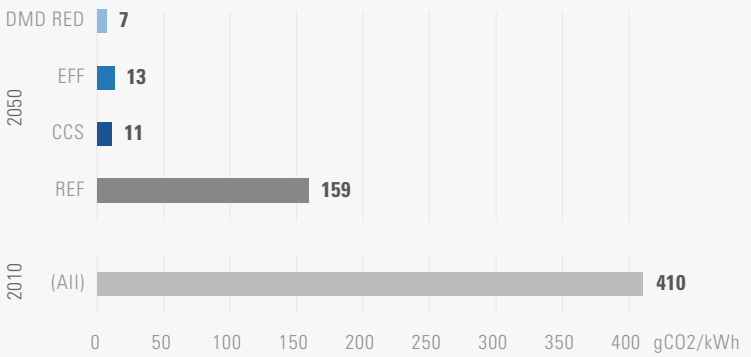
capacity in Italy. RES expansion and electrification of end-use sectors lead to an increase of the installed capacity in all DDPs, compared to the Reference Scenario. Capacity growth is even more significant because the variable RES plants have a lower availability factor than fossil fuel plants and hence lower annual production for the same installed capacity. Figure 15 gives the corresponding capacity installations across DDPs.

Figure 15 – Power capacity by source and by scenario



Source: ENEA elaboration

Figure 16 – Electricity emissions intensity by 2050, gCO2/kWh



Source: ENEA elaboration

In the DDP Scenarios, the presence of higher renewable, or low-carbon, generation capacity and output enables the drastic reduction of the carbon intensity of generation (from 401 g CO_2/kWh in 2010 to 7-13 g CO_2/kWh in 2050) in parallel with a significant carbon intensity reduction in end uses driven by electrification (Figure 16). The DMD_RED Scenario has a lower carbon intensity of generation than other DDP Scenarios (7 g CO_2/kWh) due to a lower electricity demand and lower generation (-14% with respect to the CCS scenario).

2.3.3 *Final Consumption and Emissions by Sectors*

As discussed in previous sections, electricity plays a central role in the decarbonization of the end-use sectors, but it is not the only significant contributor. While electricity demand is projected to rise in all decarbonization scenarios, net final energy savings are realized in other energy carriers. In fact, to achieve the annual emission reductions needed for deep decarbonization, strong energy efficiency improvement would be necessary in key end–uses (buildings, lighting, cooling and heating, appliances, and industry). Fuel switching towards electricity and renewables sources would not suffice.

A different picture emerges in the DMD_RED Scenario, where the energy demand reduction is due not only to a more rational use of energy, but also to a contraction in the most energy intensive industrial productions, and to behavioral changes in response to higher energy prices.

Greater sobriety in consumption patterns indeed reflects the latest changes in the Italian energy system, which diverge from previous trends. These changes include:

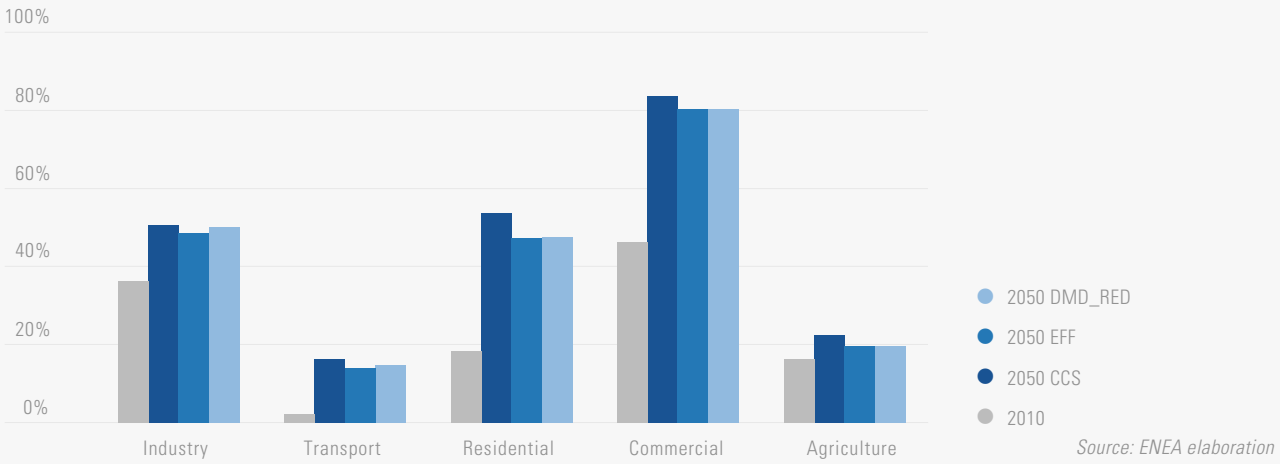
- a smaller increase in energy-services demand than in the past (different production rates, lower population growth, and slower diffusion of energy technologies for saturation levels now achieved in different segments, e.g. electrical appliances);

- an improvement in the average performance of end-use devices, as a result of technological innovation, market factors, and minimum performance standards (product certifications, eco-labeling, energy labeling, minimum performance of buildings).

Even the Reference Scenario envisages significantly lower energy demand growth rates in the end-use sectors than that of the last two decades (0.7% per year from 1990 to 2010 and 0.2% per year from 2010-2050).

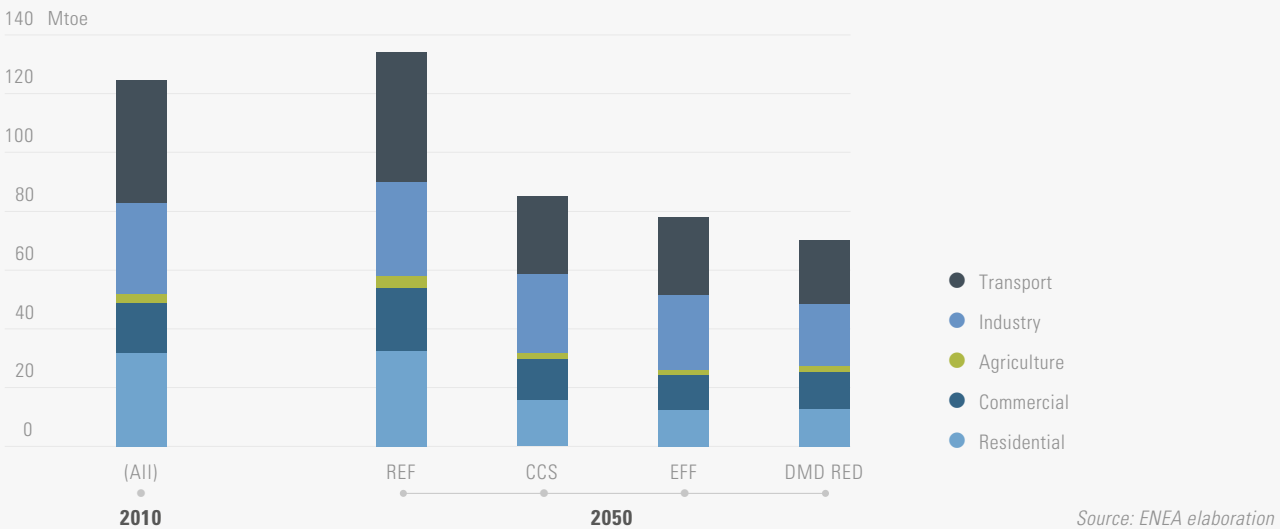
All DDP scenarios show that there are several opportunities to significantly contract energy demand in all end-use sectors to meet the decarbonization targets. Specifically, final consumption can be reduced in the long term by

Figure 17 – Electrification by end-use sectors



Source: ENEA elaboration

Figure 18 – Final Energy Consumption by sector in 2050



Source: ENEA elaboration

up to 48%, compared to the Reference Scenario. The biggest consumption drop occurs in the DMD_RED Scenario (-48%). The availability of CCS in industry, and greater use of renewable sources, can provide a higher level of energy consumption in the CCS Scenario (-36% of the Reference Scenario). The EFF Scenario assumes an ambitious increase in energy efficiency and fuel switching from fossil fuel to renewable sources, yielding 42% lower energy consumption in 2050, compared to the Reference Scenario.

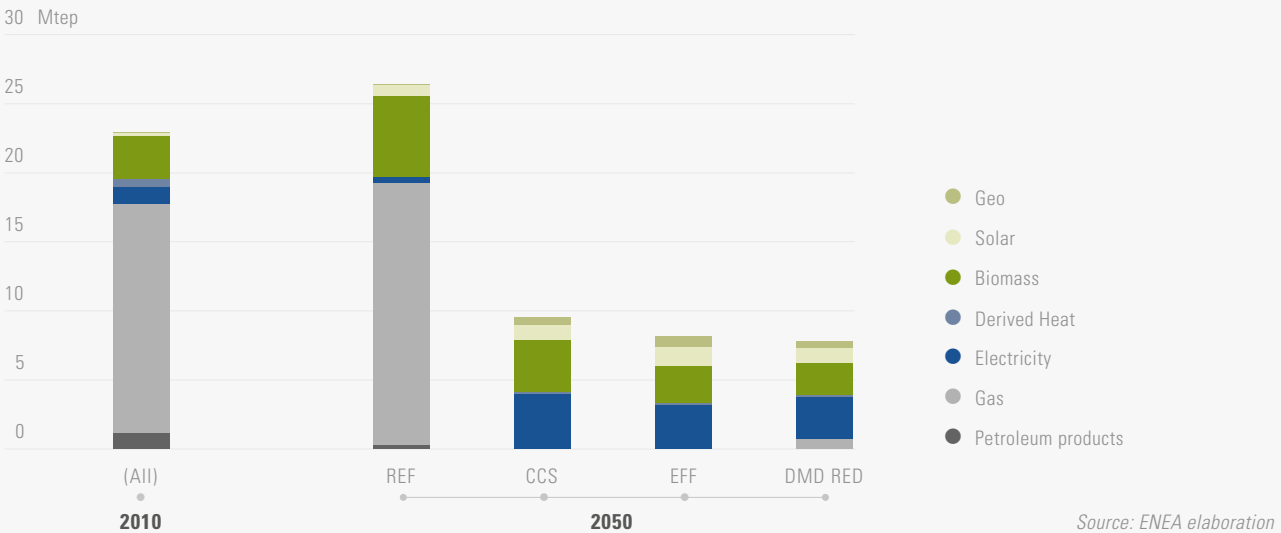
All sectors contribute to energy efficiency, albeit in varying proportions depending on the scenario: over the period modeled, the residential and service sectors account for about half of the differences between the DDP scenarios (48% to 53%) and the Reference. Transportation accounts for about one-third (31% to 35%) and the industrial sector accounts for the remaining 12% to17%.

Residential and Service Sector

CO_2 emissions in the households and services sectors can be reduced by up to 90% to 95% compared to 2010, depending on the DDP considered (Figure 19). This results from increased energy efficiency, building retrofitting, and the switch from fossil fuels to electricity and renewable energy.

In the Reference Scenario, final energy demand growth in the residential and service sectors slows down compared to past trends. This is attributable to a low population growth rate and to an ambitious portfolio of policies and regulatory provisions, such as the Energy Performance of Buildings Directive. Already in the short to medium term, all of the DDP Scenarios adopt several technological options that allow for reducing fuel consumption by 12-16 Mtoe in 2030, compared to the Reference Scenario. In 2050, the DDPs scenarios show a differential in energy consumption with the Reference Scenario ranging between 26 Mtoe (CCS Scenario) and 32 Mtoe (EFF Scenario). These reductions can be attributed primarily to thermal uses (heating, hot water, and cooking), currently responsible for over three-quarters of energy use. In this segment, it is possible to halve consumption through energy efficiency measures, such

Figure 19 – Heating&cooling consumptions by sources in residential sector



Source: ENEA elaboration

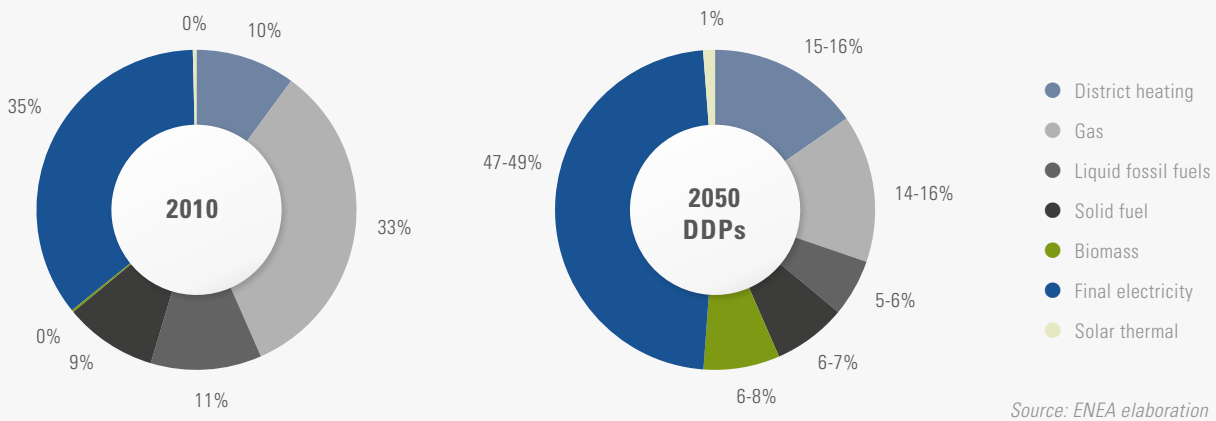
as significant improvements in average building performance, achieved through both high-efficiency heating technologies and building retrofitting. In fact, in 2050 between one-fourth and one-third of the demand for heating could be reduced through improved thermal insulation of buildings (about 9 million retrofitted buildings). Decarbonization also occurs due to fuel switching: biomass boilers, solar heating systems, and heat pumps allow for meeting one-third of the residential and service sectors' energy demand in 2050. The envisioned decarbonization of the residential sector is almost complete and, in the heating and cooling segment, fossil fuels will play a role by 2050 only in the DMD_RED Scenario. The DMD_RED Scenario is characterized by changes in lifestyles and industrial activity related to higher energy prices, compared to the Reference Scenario. So the effort towards emission reduction is redistributed among all sectors, depending on the sectoral energy commodity prices.

The electrification of final consumption also plays a crucial role in decarbonization. In the medium term, the demand growth for electricity services is compensated for by improving the performance of appliances (including air conditioners and "white" appliances). Instead, in the long term, the deployment of electrical technologies for thermal uses (such as heat pumps and electric cookers) leads to a further increase in electricity in the CCS Scenario (up to 240 TWh).

Industrial Sector

The industrial sector shows an emission reduction between 33-36 Mt CO_2 compared to the Reference Scenario in 2050 and 50% to 55% lower emission than 2010. Energy efficiency and electrification are key pillars also for decarbonizing the industrial sector, but to reach strict targets, the availability of CCS is a crucial asset. In all the DDP Scenarios, fossil fuels in industry are replaced by electricity and renewable sources (in particular biomass and renewable waste). The fuel mix is almost the same across the three DDP Scenarios. By construction, the main difference in these scenarios is CCS availability. This technology can be used in industrial sectors (particularly in the iron and steel and cement industries) to capture and store CO_2 process emissions. A higher use of CCS allows greater consumption of fossil fuels and less improvement in efficiency in the CCS

Figure 20 – Energy mix in the industrial sector, 2010 and 2050



Source: ENEA elaboration

scenario then in the other DDPs. This does not affect the share of fossil fuels, but results in large final energy demand differences among the alternative DDPs. In fact, compared to the Reference Scenario, industry reduces energy demand by 18% in the CCS Scenario, 22% in the EFF Scenario, and by as much as 34% in the DMD_RED Scenario. That is, respectively, 14%, 19% and 32% less than in 2010.

The scenarios show that in the energy intensive sectors, the availability of commercial-scale CCS could allow maintaining a viable manufacturing sector in intermediate goods instead of losing a significant part of it, for instance, through delocalization (as in the DMD_RED Scenario). In the CCS scenario, in 2050, almost 19 million tons of CO_2 are captured and not released into the atmosphere. Moreover, in the iron and steel sector, a consistent share of blast oxygen furnaces is replaced with electric arc furnaces.

In the EFF and DMD_RED Scenarios, steam and heat consumption is roughly the same as in the Reference Scenario. In the CCS Scenario, steam consumption increases by about 21%.

Transport sector

The transport sector could avoid between 65-76 Mtons of CO_2 compared to the 2050 Reference level by using electrical and hybrid vehicles, alternative and eco-sustainable fuels, and modal shift towards collective mobility (Figure 21).

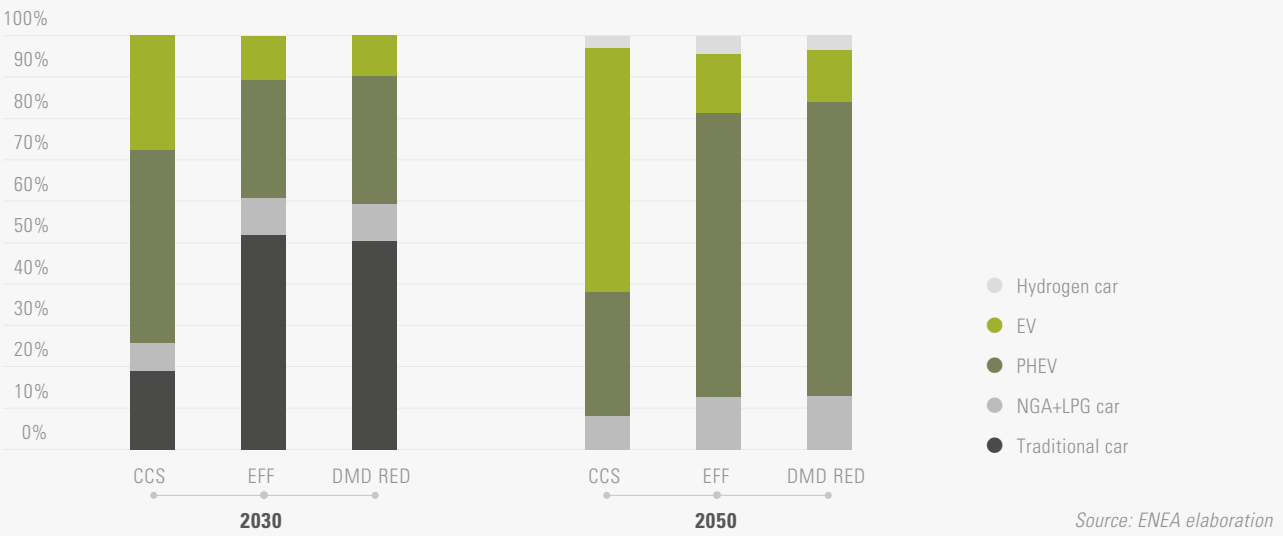
The shift from conventional cars to electric vehicles and plug-in hybrids and the shift from road to rail transport (modal shift) lead to a major increase in electricity demand in the transport sector.

In 2050, EV[34] and PHEV[35] account for about 90% of road passenger transportation in all DDPs, but already in 2030, the CCS Scenario projects a significant share (about 70%) of electrical cars. The CCS scenario allows such a high level of electric vehicles diffusion through the wide availability of renewables sources and CCS technology, allowing more electricity production. The main levers for carbon abatement in freight transportation are alternative fuels in-

34 Electrical Vehicles.

35 Plug-in Hybrid Electrical Vehicles.

Figure 21 – Demand for road-based passenger mobility by type of cars



Source: ENEA elaboration

cluding biofuels such as bio-methane, and LNG. Also significant is the modal shift from road transport to train and navigation.

2.3.4 Costs and Investments Needed

The DDPs require considerable effort in terms of low carbon resources and technologies, and also in economic terms. Compared to the evolution that takes place in the Reference Scenario, the cost changes are significant (Figure 22). In particular, the emphasis switches from fossil fuel costs and operating costs towards investments in power generation capacity and more efficient technologies and processes.

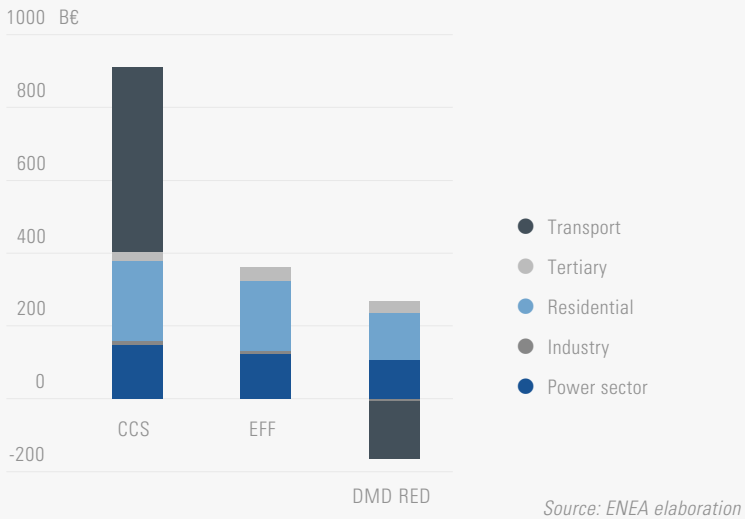
The CCS scenario has 30% higher cumulated net costs over the period 2010-2050, compared to the Reference Scenario (Figure 22). These are mainly due to the adoption of more expensive electric technologies (such as electric cars or heat pumps). They are especially costlier in the short- to medium term.

As mentioned, grid infrastructure and transportation costs (railways, seaport, etc.) as well as investments in trains, ships, and aircraft are not accounted for in this analysis. This means that what we present here represents a lower bound estimate of the costs associated with the DDPs. Incremental costs in the industrial sector are related to the investment costs of advanced processes in all DDPs, and also to the costs of investing in carbon-capture and storage in the CCS Scenario. Even the end-use electrification leads to more expensive investments, like the cost increase of investment in the commercial sector, which is the one with a higher electrification by end use.

The buildings sector has higher net investments compared to the Reference Scenario by about 50% in the CCS Scenario, 45% in the EFF Scenario, and 35% in the DMD_RED Scenario. In the buildings sector the higher net costs for CCS and EFF are associated with increased use of heat pumps and retrofitting buildings.

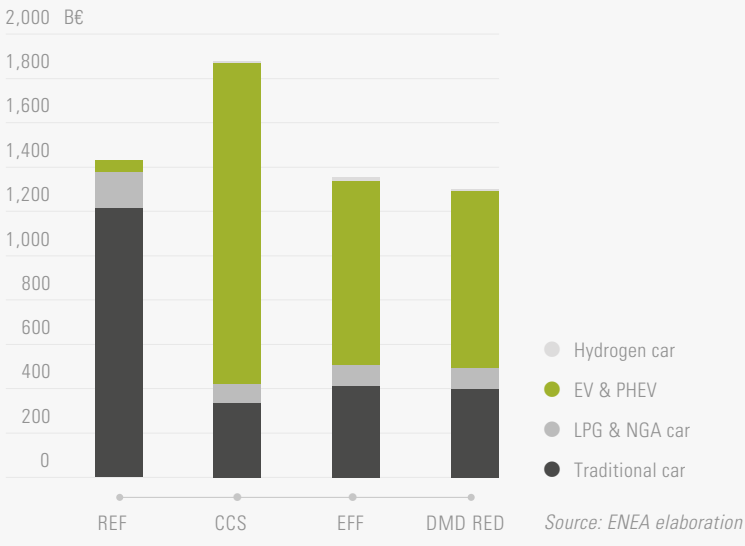
Figure 22 shows that the EFF and DMD_RED Scenarios require similar investment levels, excluding the transport sector. In fact, the DMD_RED Scenario produces lowest cost in the transport sector due to the contraction of passenger and freight transport demand (Figure 23).

Figure 22 – Cumulated costs change in three scenarios vs reference, 2010-2050



Source: ENEA elaboration

Figure 23 – Cumulated costs of passenger cars in the period 2010-2050



Source: ENEA elaboration

Figure 24 – Net-fuel import change of three DDPs vs Reference scenario

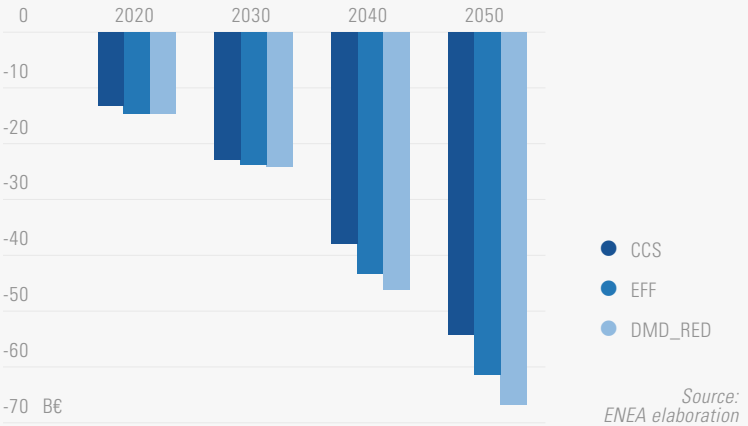


Figure 25 – Power generation costs of new capacity plants, 2010-2050

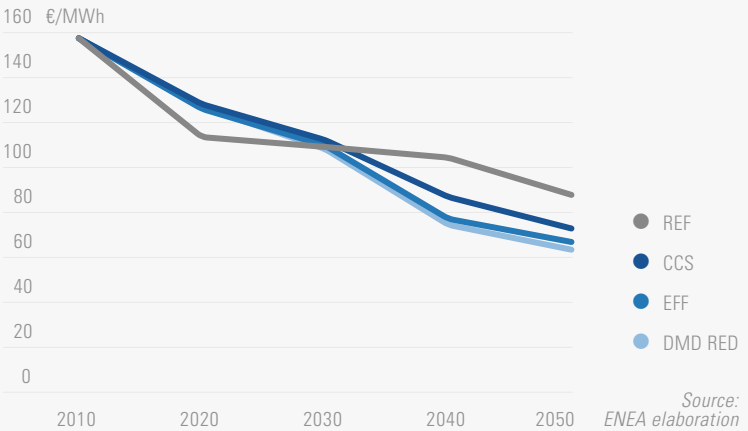
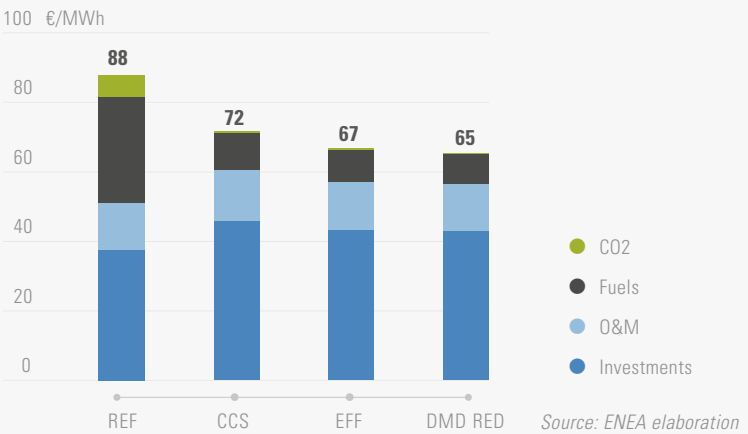


Figure 26 – Power generation cost components



The CCS Scenario is characterized by a high investment cost increase in passenger mobility: electrical vehicles, besides presenting higher capital unit costs, have shorter commercial life and lower average mileage compared to traditional cars, especially in the medium term.

As a result of energy efficiency improvements and the shift from fossil fuels to RES, the expenditure for energy imports decreases significantly in all DDPs: even in 2020, Italy's energy bill could be reduced by more than 10 billion Euros compared to the Reference projections (Figure 24). In 2050, the decarbonization process results in a massive contraction of the net fuel import bill: the reduction in the CCS Scenario compared to the Reference Scenario is around 54 billion Euros. In the EFF and the DMD_RED Scenarios, such reductions are more significant, around 61 and 67 billion Euros, respectively.

The cost of the electricity generation estimated in this analysis include technology investments, O&M costs (variables and fixed), fuel costs, and CO_2 value in the ETS. Transmission and distribution costs are not accounted for.

Figure 25 shows higher cost of electricity generation in all DDPs until 2030, but a greater cost-effectiveness of the highly decarbonized power generation sector in the longer term. This evolution is influenced by the strong penetration of renewable energy plants in the DDPs. This adds large investment costs, which are more than offset by a reduction in variable fuel and maintenance costs compared to the Reference Scenario. Indeed, the Reference Scenario requires new fossil fuel capacity in the medium-to-long term. In the Reference Scenario, fossil fuel costs and investment costs are the most important components of generation costs (Figure 26).

In the CCS scenario, generation costs are higher than in other DDPs for several reasons. First, CCS capacity expansion implies higher investment

and O&M costs than most renewable plants. Second, plants equipped with CCS are less efficient than non-CCS plants, as CO_2 capture and storage processes require energy and hence have reduced net output. Finally, CCS implies that the economy still incurs fossil fuel costs.

The EFF and DMD_RED Scenarios are characterized by similar power generation mixes. A high share of renewable energy plants in both help to drastically reduce fuel expenditure and the costs associated with CO_2 emission (carbon price).

3 Macro-economic analysis

3.1 Macro-economic Scenario Construction

Two multi-sector Computable General Equilibrium (CGE) models, GDyn-E and ICES (described in details in the Appendix), are used to evaluate the macroeconomic implications of the transformation required to achieve the DDPs as characterized by TIMES-Italy in the previous Section.
Both CGE models have been aligned with TIMES-Italy in terms of geography (Italy versus rest of the world), and time horizon (2010 to 2050). For Italy, GDyn-E and ICES have used common macroeconomic projections (GDP, population, labor force). Italian CO_2 emissions, total primary energy mix, and fuel prices have also been aligned for each scenario. For the rest of countries, macroeconomic drivers (GDP, population, labor force) and CO_2 emission reductions pathways to 2050 come from external official sources as summarized in Table 5. EU emission projections come from EU Energy Transport and GHG emissions trends to 2050 – Reference scenarios 2013 (EC, 2014). Emissions of other countries are based on the IEA ETP 4°C Scenario (4DS). The 4°C Scenario (4DS) takes into account recent pledges made by countries to limit emissions and to improve energy efficiency.
In the decarbonization scenarios, GDyn-E and ICES have been harmonized with TIMES-Italy with respect to Italian CO_2 emissions, primary and final energy. As for the decarbonization pathways for all other countries, they are based on the ETP 2 °C scenario (2DS). The decarbonization scenarios explore three alternative pathways to achieve the 80% decarbonization in Italy with respect to 2010[36]. Note that the analysis fo-

Table 5 – Summary of sources for main scenario assumptions

Region	Source					
	CO_2 emissions		GDP	Population	Labor Stock	Primary Energy Mix
	REF	DDP (2DS)				
Italy	TIMES – Italy	TIMES - Italy	EC	W. Bank	ILO	TIMES - Italy
European Union	EC	ETP	EC	W. Bank	ILO	EC/ETP*
World	ETP	ETP	ETP	W. Bank	ILO	ETP

** In line with emissions data, the source for primary energy has been European Commission for baseline scenario and Energy Technology Perspectives for decarbonization scenarios.*

36 Global emission reductions in 2050 for the three policy scenarios is 54 % relative to 2010, and 31% relative to 1990 levels.

cuses on CO_2 combustion based emissions from fossil fuels and industrial sources, whereas the mitigation potential of agriculture, land-use and forestry is not considered.

As described in Section 2, the CCS Scenario is characterized by slightly greater decarbonization due to the higher electrification with renewable energy sources and coal and gas technologies coupled with Carbon Capture and Storage (CCS) from 2025 onward. The EFF Scenario combines a slower decarbonization of the electricity system due to a lower penetration of CCS with more energy efficiency and use of renewable energy in transportation and heating. Finally, the DEM_RED Scenario considers a lower commercialization of CCS technologies and a contraction of energy intensive industries.

GDyn-E and ICES provide two alternative modelling approaches to the three major technology components of the decarbonization scenarios, namely the contribution of renewable energy sources (RES) to primary energy supply, the penetration of CCS, and energy efficiency improvements. What follows is a brief description of how each model represents the three components of decarbonization strategies.

Renewable energy

In GDyn-E the contribution of renewable energy sources is modelled by using three main approaches. First, a carbon tax revenue recycling scheme has been introduced to finance R&D in the electricity sector.[37] The R&D fund increases output-augmenting technical change in the electricity sector, which would need less fossil fuel in power generation. Second, in the electricity sector the elasticity of substitution between capital and energy is increased, in order to model wind and solar, which are the prevailing and capital-intensive renewable energy sources. Third, in all sectors the substitution elasticity between electrical and non-electrical energy has been increased, to foster the use of more capital-intensive electricity.

In ICES, renewable energy has been modelled as an additional power generation sector and calibrated to reproduce the primary energy consumption in all regions of the world for 2010, according to the IEA's world energy balances dataset (IEA, 2014).[38] From 2010 onwards, RES behave following the trends suggested by TIMES-Italy. In the different DDP Scenarios, the greater use of renewable sources for heating and transport has been represented by increasing the substitution possibilities between primary energy sources and electricity.

Carbon Capture and Storage Technologies

In GDyn-E, CCS technologies are modeled by introducing a technical coefficient which modifies coal emissions and by increasing the elasticity of substitution between the aggregate coal- and non-coal- energy. In particular, in line with CCS deployment from TIMES-Italy, the technical coefficient almost eliminates CO_2 emissions from coal combustion. The elasticity of substitution in the coal-non coal energy nest of the production function is increased to mirror the increased convenience to use coal in the decarbonization scenarios.

In ICES, power generation with CCS is an explicit electricity generation sector. The technology for capturing and storing CO_2 emissions is assumed to reach mature development in 2025.[39] The model assumes that CCS can operate with both coal and gas.

37 Further details on this revenue recycling scheme, as for the other scheme related to energy efficiency modeling, can be found in Antimiani et al. (2015b).

38 IEA (2014), "World energy balances", IEA World Energy Statistics and Balances (database). DOI: http://dx.doi.org/10.1787/data-00512-en.

39 The details of the inclusion of this technology are described in the ICES description Box.

Energy efficiency

In GDyn-E, energy efficiency is modelled using a similar approach to that used for renewables and by implementing a revenue recycling scheme. In this case, the R&D fund financed by the carbon tax is assumed to increase the efficiency in fossil energy use in all industrial sectors as well as in the residential sector. In this case, the model assumes that improvements in the technical change parameter is the outcome of R&D efforts. This allows a reduction of the energy inputs needed to provide energy services. This means that while in the electricity sector, technical change is output-augmenting, in the other sectors it is energy-biased and it increases only the productivity of energy inputs.

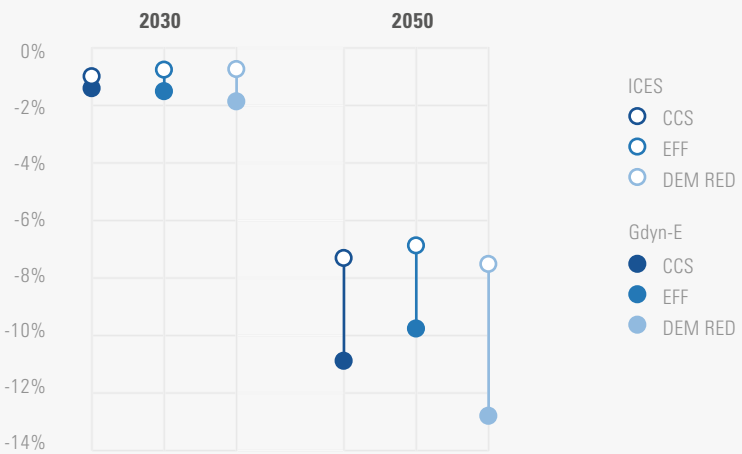
ICES represents autonomous improvements in energy intensity in decarbonization scenarios by assuming exogenous trends for energy productivity. In addition, a greater improvement in energy intensity is facilitated by a higher substitutability between capital and energy in all sectors, a process that mimics the introduction of more energy-efficient machinery and equipment. In the DEM_RED Scenario, coal and gas with CCS jointly account for only about 3% of electricity generation in 2050 and more effort should be undertaken to improve the energy efficiency in industries.

3.2 Results

3.2.1 GDP and Sectorial Value-Added Impacts

Transforming the economy to achieve any DDP will induce changes in the main macroeconomic aggregates starting early on, in 2020, which will become more pronounced over time. Relative to the more moderate emissions reductions in the Reference Scenario, Gross Domestic Product (GDP) would be between 1% and 2% lower in 2030, but mitigation costs would increase rapidly afterwards (see Figure 27). Macroeconomic costs, measured in terms of GDP percentage change relative to the Reference Scenario, do not vary significantly across the three alternative pathways, between 7% to 13% in 2050. Both models focus on a domestic implementation of the 80% reduction target. This provides an assessment of the unilateral cost of decarbonizing the economy in a context in which all countries in the world make similar efforts at mitigation, but do not exploit linkages or coordinate efforts.[40]

Figure 27 – GDP change relative to the Reference scenario in the three decarbonization pathways



GDP relative to the referenece scenario

Source: FEEM and ENEA elaboration

40 Given the EU political framework, ICES also evaluates the economic implications of the Italian decarbonization pathways in the context of a common policy for EU, and for completeness, also in the context of a globally coordinated effort through global carbon market. The costs mentioned in this report assume that Italy meets the decarbonization effort domestically. However, if Italy could buy permits on a European or even a global carbon market, the domestic emission reduction would be less than 80% as Italy would be a net buyer of carbon permits. The possibility of exploiting cheaper mitigation options in other EU countries could reduce the policy costs significantly up to 60% in 2050. Expanding the possibility of purchasing carbon credits or emission permits on a fully-fledged global market could reduce costs even further, with possible gains occurring after 2020. Results are available upon request.

Decarbonization has larger macroeconomic impacts in GDyn-E. What explains this is the absence of an explicit representation of RES in the model. Moreover, the more limited flexibility in replacing fossil-fuel energy with renewable sources in GDyn-E leads to a greater sensitivity to how decarbonization pathways are implemented. The DEM_RED Scenario induces a relatively larger reduction in GDP, whereas in the EEF Scenario, the strong improvements in energy efficiency mitigate the negative impacts on GDP. The economic costs of implementing the DDPs are in the range of cost estimates from CGE models in previous mitigation modelling exercises for Europe. Knopf et al. (2014), for instance, use a set of different models to evaluate the macroeconomic implications of the European 2050 Roadmap. The study shows that European GDP could be reduced by between 1 and 10% (median estimate 4%) in 2050. Mitigation costs are influenced by perspectives on future technological change, structural transformation, and substitution possibilities across production factors and sectors, as also shown by the different cost estimates provided by the two models. CGE models generally provide upper bound estimates of the macroeconomic costs of climate policy scenarios like the ones considered in this report because: 1) future policy changes cannot be anticipated, and 2) the extent to which future breakthrough technologies can penetrate is limited.[41] Since CGE models are calibrated on historical data, the degree to which they can characterize major structural, technological, and behavioral changes is limited by models' constant elasticity of substitution (CES) structure and calibration, which is based on the current reality. Note also that this analysis does not consider mitigation options that allow for negative emissions, such as biomass combined with CCS or REDD. Moreover, the analysis does not include the benefits of action in terms of avoided climate change impacts, nor does it account for other possible co-benefits (e.g., reduced health impacts from the combustion of fossil fuels, dynamic efficiency gains in terms of innovation, human capital, job creation).[42]

Per capita GDP increases in all Scenarios but is higher in the Reference Scenario than in the three DDPs (Table 6).

Similarly, annual growth rates in all Scenarios are positive. Table 7 shows the GDP average annual growth rate, which is slower in the DDP Scenarios compared to the Reference Scenario by 0.18% to 0.35% per year, for the period 2010-2050.

Figure 28 shows the percentage point difference in GDP and sectoral value added in the three DDPs relative to the Reference Scenario. Besides the fossil energy sectors, the sectors of services and other industries experience a decrease in value added average growth of between 0.02% and 0.5% per year, reflecting the overall effect in

Table 6 – Per capita GDP growth to 2050 compared to 2010 levels in the three scenarios - percent

	REF	CCS	DEM_RED	EFF
ICES	70%	57%	57%	58%
GDyn-E	64%	46%	43%	48%

Table 7 – Average annual growth rate in GDP (2010-2030 and 2010-2050)

Model	Scenario	2010-2030	2010-2050
ICES	Ref	1.37	1.25
	CCS	1.32	1.06
	EFF	1.33	1.07
	DEM_RED	1.33	1.05
GDyn-E	Ref	0.94	1.17
	CCS	0.87	0.88
	EFF	0.86	0.91
	DEM_RED	0.84	0.82

41 Paltsev and Capros 2013, Knopf et al. 2014.

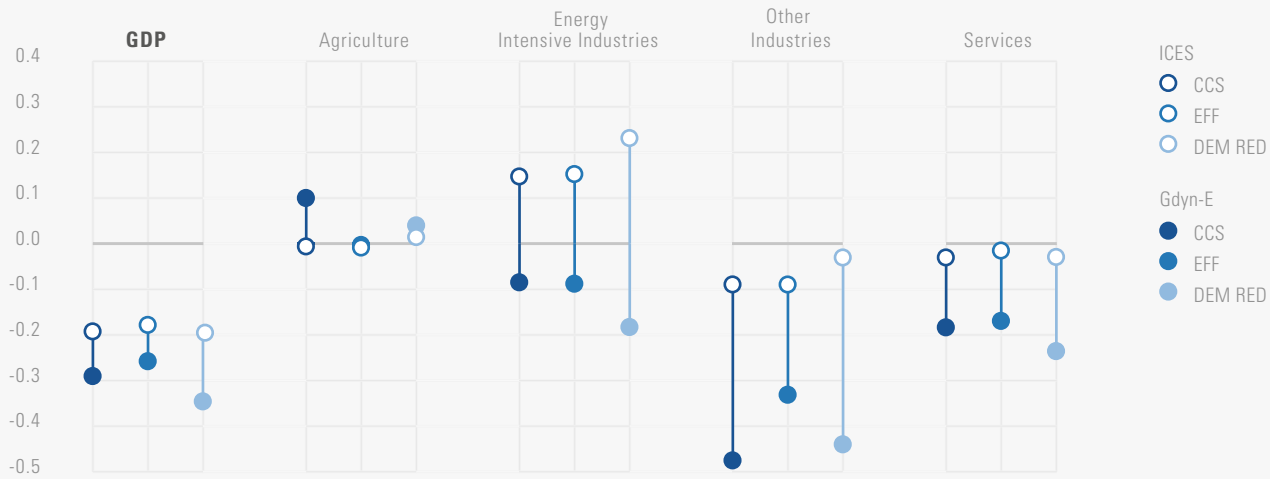
42 Hallegatte et al. 2012.

the economy. Agriculture would also experience a slight increase in average annual growth rate. Although energy intensive industries reduce final output compared to the Reference Scenario, value may not necessarily decrease, as shown by the conflicting results emerging from the two models. These are due to differences in the future structure of the economy and opportunities for technological development postulated by the two models. For example, in the ICES model the prevailing substitution effect makes it possible to substitute energy, and the use of other intermediate inputs, with more capital and labor. Higher capital-energy substitution implies more investments in energy-efficient machinery and equipment. Fossil-fuel-based energy can be substituted with renewables, compensating for the reduction in energy use that the policy induces. Moreover, the increase in RES use and CCS induces a demand-pull effect on the energy-intensive industries that supply intermediate inputs (systems and components) to electricity sectors deploying those low-carbon technologies. This effect becomes noticeable when the penetration of renewables is high enough, as is the case in the CCS scenario. Renewable sources of energy will be an essential component of a decarbonized energy system. Yet, renewable energy sources need raw materials, minerals, and inputs whose processing and production can be energy intensive. Nevertheless, life-cycle assessments of renewable energy sources indicate that the lifecycle emissions of renewables are significantly lower than fossil-fuel based sources[43]. These mechanisms could therefore lead to an increase in the energy-intensive industries' value added by between 0.15 % and 0.23%.

In the GDyn-E, model the possibility of substituting fossil-fuel-based energy with renewable sources is more limited and the scale effect tends to prevail. As a consequence, the reduction in energy demand in energy-intensive industries is more pronounced, and this limits the possibility of substituting energy with capital. The combination of these effects leads to a slight contraction of capital, an increase in labor, and

43 Sathaye et al. 2011.

Figure 28 – Average GDP and value added growth rate change relative to the Reference Scenario in the three decarbonization pathways for the period 2010-2050



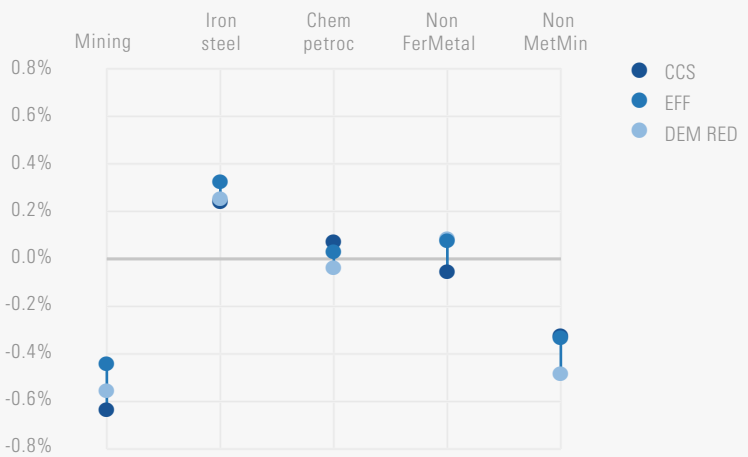
Percentage point difference

Source: FEEM and ENEA elaboration

an overall reduction in value added. The GDyn-E model has a more refined sectoral disaggregation than the ICES model (see Table in Appendix), and Figure 29 shows the impacts of deep decarbonization on individual energy-intensive industries. The aggregate contraction in the annual average growth rate is driven by the mining sector[44] and the non-metallic minerals industry. By contrast, the positive impacts of around 0.3% on iron and steel sector is associated with the greater demand for those inputs by the renewable sector, as described above.

Decarbonization scenarios would induce a structural change in the economy that would benefit the electricity generation sector and energy-intensive industries (see Table 8 in the appendix for the industrial classification). Although these sectors experience an increase in value added, this does not show in the aggregated costs (Figure 28), given their low shares of GDP (less than 5%). In both models, the share of agricultural GDP will remain low, as in the Reference Scenario, while the share of other industries and services will increase slightly.

Figure 29 - GDyn-E model - energy intensive sectors value added change relative to the Reference Scenario in the three decarbonization pathways



% change relative to reference

Source: ENEA elaboration

3.2.2 *International Competitiveness and Trade*

As mentioned in Section 1.4, 80% of the energy required, in particular oil and gas, is imported from abroad. The transition away from fossil fuels towards renewables sources will help reduce the Italian dependence on imported sources of energy, but to different degrees in the three DDPs (Figure 30). In the CCS Scenario, the availability of CCS technologies would imply greater fossil fuels use than in other decarbonization scenarios, particularly coal. In this scenario, coal imports would only be reduced by between 25% and 45%, as opposed to the greater reduction rates for oil (up to 70%) and gas (up to 92%). The other scenarios are characterized by a reduced use of CCS, which further lowers fossil fuel imports. They could fall by up to 92%, compared to the Reference Scenario.

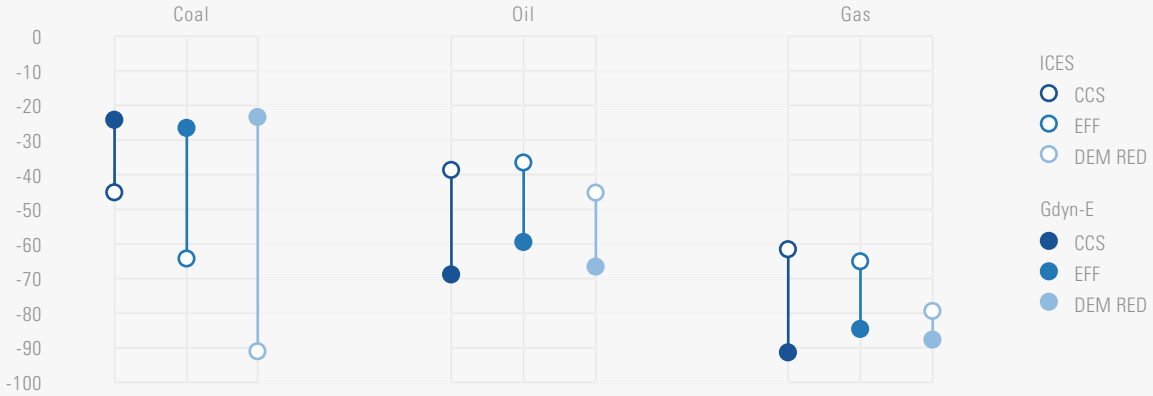
Deep decarbonization would impact imports in all industries and sectors. The extent of the impact, however, is smaller in magnitude relative to fossil fuel energy sources (Figure 31). Moreover, as indicated by the reported differences between models, the extent to which industrial imports will be affected depends on the future structure of the economy, and on the opportunities for substitution and technological development. A greater reduction in all imports is reported by the GDyn-E model, which, as mentioned above, has a lower flexibility.

3.2.3 *Employment*

The transformation into an economy that relies more on clean and renewable energy sources will induce structural changes, stimulating production in the industries that supply inputs to the renewa-

44 The mining sector includes mining of uranium and thorium ores, mining of metal ores and other mining and quarrying (ISIC Rev. 3 Code, n.12,13,14).

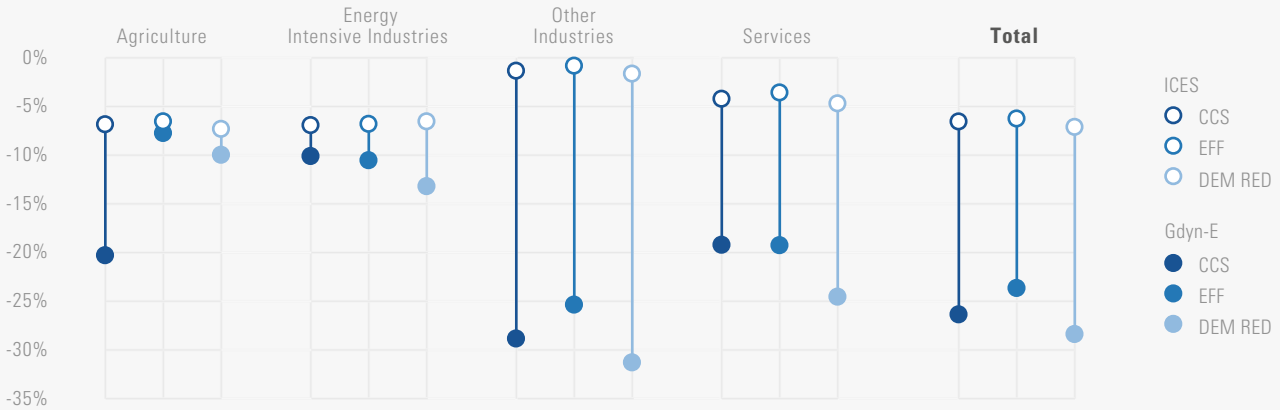
Figure 30 - Fossil energy Imports in 2050. Percentage change relative to the Reference Scenario



Percentage change relative to reference

Source: FEEM and ENEA elaboration

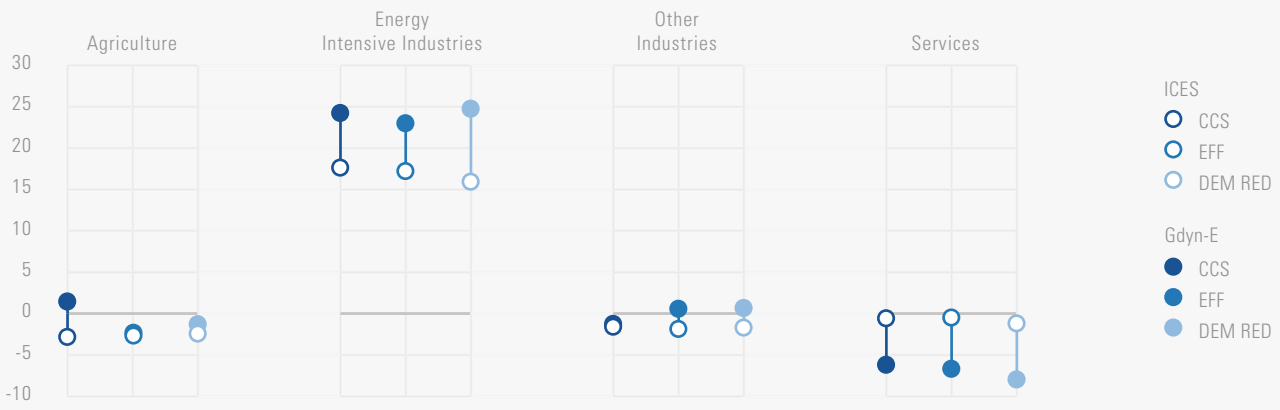
Figure 31 - Imports in 2050. Percentage change relative to the Reference Scenario



Percentage change relative to reference

Source: FEEM and ENEA elaboration

Figure 32 - Changes in labor demand in 2050 relative to the Reference Scenario



Percentage change relative to reference

Source: FEEM and ENEA elaboration

ble energy sector. These adjustments will also lead to a reallocation of employment across sectors.[45] The deep decarbonization process will induce a significant downsizing of fossil-fuel-related sectors including extraction, refining, and commercialization. Employment will increase in renewable energy generation, and in the industries providing raw materials, metals, and inputs for a low-carbon economy. Figure 32 describes the distributional effect of deep decarbonization pathways across four aggregated sectors. Energy-intensive industries will also increase the demand for labor in 2050, relative to the Reference Scenario. This is due to the substitution effect and the demand-pull effect highlighted above. The rest of the economic activities (agriculture, other industries and services) would reduce their labor demand by less than 10%. In GDyn-E, higher employment in energy-intensive industries is mainly due to an increase in the demand for labor in iron and steel. By contrast, there is a reduction in the mining sector and a small percentage change in the remaining sectors, namely chemical products, non-ferrous metal, and non-metallic minerals.

Table 7 shows the percentage change in the unskilled and skilled labor demand by sector in the three DDP scenarios. Agriculture is the only unskilled labor-intensive sector; the others are all skilled labor-intensive, with the share of skilled labor reaching almost 90% in services. For both models, the shares of skilled labor as a fraction of total labor remain almost unchanged in the DDP scenarios relative to the Reference.

Table 8 – Changes in labor demand in 2050 relative to the Reference Scenario case and skilled versus unskilled labor composition.

%	Percentage change relative to the Reference Scenario (ICES/GDyn-E)			
	Agriculture	En_Int_ind	Oth_ind	Services
CCS				
UnSkLab	-2.91/1.29	19.10/16.89	-0.41/-1.85	0.85/-9.44
SkLab	-3.3/1.92	16.92/27.58	-2.31/-1.22	-0.99/-5.88
EFF				
UnSkLab	-2.98/-2.68	18.75/17.78	-0.62/0.06	1.18/-8.76
SkLab	-3.4/-2.29	16.41/25.38	-2.66/0.74	-0.81/-6.54
DEM_RED				
UnSkLab	-2.57/-1.44	17.23/18.04	-0.54/-0.03	0.94/-10.70
SkLab	-2.95/-0.89	15.17/27.93	-2.37/0.93	-0.8/-7.62

45 It is worth considering that in both CGE models the policy scenarios have been run under a full employment assumption, so these comments should be interpreted as referring to employment reallocation and not to new job creation.

4 Discussions and conclusions

This report presents alternative pathways to decarbonize the Italian energy system that aim at reducing 2050 emissions to 80% (compared to 1990). Scenario analysis, based on models of Italy's energy and economic systems, provides a consistent assessment of possible impacts on key energy and macroeconomic dimensions, and can help to identify stress points and robust strategies.

From the energy system point of view, the three pathways considered are technologically feasible. Incremental energy system investments vary across the three scenarios: the CCS scenario is the most costly, while the other two require smaller investment efforts. Deep Decarbonization Pathways (DDPs) imply significant decreases in fossil-fuel energy imports, reducing import dependence. Given the characteristics and challenges of the Italian energy system, successfully implementing the DDPs would rest on deploying solar and wind technologies, a significant contribution from biomass generation, and a moderate but critical role for CCS. Moreover, the transformation of the energy system will have to be accompanied by the deployment of more efficient technologies in a number of industrial sectors within the Italian economy, as well as in transport and residential energy uses. All DDPs imply significant reductions in energy intensity (between 2% and 2.4% per year) and in carbon intensity (between 3% to 3.2%). Achieving these reduction rates will require a significant acceleration, compared to the historical trends observed for the period 2000-2010, when energy intensity and carbon intensity decreased at an average annual rate of only 0.3% and 1.1%, respectively.

The transition towards a decarbonized economy will entail structural adjustments and the macroeconomic implications are not negligible. The macroeconomic analysis described in this report provides an assessment of the cost of decarbonizing the Italian economy. In the three scenarios considered, GDP deviations from the Reference Scenario increase rapidly over time. If the DDP scenarios considered the possibility of trading carbon allowances with other European countries, such as in the EU ETS scheme, macroeconomic costs would be reduced up to 60% in 2050 compared to unilateral implementation. Participating in a global carbon market would reduce costs even further.

The report's macroeconomic analysis shows that decarbonization will have heterogeneous impacts across sectors, inducing a reallocation of resources and employment towards sectors related to a low-carbon economy. It is worth mentioning that these cost estimates do not consider potential ancillary benefits nor the avoided impacts of climate change.

Whether or not Italy is successful in decarbonizing the energy system rests on whether all technology options are available, and on the political support provided for the energy transition. In this respect, two key questions arise:

Are currently available technology options sufficient to achieve this target? What will be the role of international technology cooperation?

From a technological point of view, the decarbonization of the energy system appears feasible, with a few key hurdles to overcome. For instance, Italy has access to the technology options needed. Renewable energy technologies, such as wind, solar, and biomass, are largely available on the European and global market. Renewable energy penetration has increased dramatically in Italy in recent years, and further deployment is possible. Technology costs have been decreasing for all renewables, and both wind and solar PV are close to being cost competitive with traditional fossil-based generation options. A number of studies point to the potential for further cost improvements before 2030 through both R&D

investments[46] and learning-by-doing.[47] Among the technologies considered in the three DDPs, the least mature is CCS. CCS is still at the development stage, and Italy is one of the few countries where pilot plants have been established.

Five major technological challenges that might hinder the future transformation of the energy system can be identified, and some viable recommendations can be made:

1. It is necessary to develop a secure system for offshore wind production which meets the requirements of the sites where they can be deployed in Italy. Offshore wind significantly contributes to primary energy supply in all the DDPs. As mentioned in Section 2, offshore wind farms are still at the project stage and their deployment along Italian coasts faces significant technical challenges.
2. A key concern is whether it is possible to produce enough biomass to cover between 16% and 19% of net electricity generation. From a technical point of view, biomass is a flexible renewable energy option, it is dispatchable, and does not require any major change in the paradigm of electricity production. Currently, a significant portion of biomass used in electricity generation is constituted by residual biomass and waste, including urban waste. Policies encouraging alternative uses of that biomass might reduce the amount available for power production. Even if the three DDPs for Italy rely on the assumption that most of the biomass is imported, considerations about the sustainability of such production should also be factored in to avoid negative environmental and economic impacts globally. Technical experts, policy makers, and the wider public are concerned about the dangers and possible conflict over land use changes because of the importance of food production, and the possible repercussions on other aspects of human life. In this respect, the development of third generation biomass technologies represents an attractive option.[48]
3. A high percentage of intermittent renewables, such as wind and solar, needs to be included in the grid and managed. This requires the modernization of the electric grid to handle variable and distributed electricity generation[49,50]. This is an important challenge, which has been only partly explored in this report due to the nature of the models used. For instance, in 2009, a number of wind farms operated at 30% less than their normal capacity, due to the shortage of transmission capacity through the existing grid. This can be a major issue as solar and wind energy generation are highly concentrated in areas where the grid has low capacity, such as the southern regions of Italy. The large development of non-dispatchable generation, along with a progressive reduction of fossil-fueled thermal power, could make it difficult to ensure adequate reserve margins and regulating capacity for the secure operation of the system and the stability of the grid. This problem can be addressed in several ways:
   - By extensively upgrading of the power grid, increasing the interconnection of market zones, and strengthening the ability to transport electricity from areas with excess supply to areas of higher demand.
   - By installing storage systems or other low-carbon balancing capacity, such as pumped storage hydro, thermal storage, bat-

46 IEA Technology Roadmap: Solar Photovoltaic Energy - 2014 edition, IEA Technology Roadmap: Wind Energy - 2013 edition

47 Witajewski et al. (accepted), "Bending the Learning Curve", Energy Economics forthcoming

48 Fiorese et al. "The Power of Biomass: Experts Disclose the Potential for Success of Bioenergy Technologies", Energy Policy 2013

49 Gaeta M. "Electricity and the grid" pp 177-188, Green and energy technologies - Springer series 8059, 2012.

50 https://www.irena.org/DocumentDownloads/Publications/GWEC_Italy.pdf

teries, or hydrogen storage with fuel cells, especially in the South.

- By developing smart distribution networks that can cope with the wide diffusion of distributed generation.

4. From this perspective, the development of fast-charging infrastructure for electric vehicles would increase efficiency in the transport sector and could also help stabilize the grid at times of peak generation from renewables and reduce excess production. However, the need to provide adequate infrastructure for load balancing should not be overlooked.
5. Concerns exist over the viability of CCS. The uncertainties stem not so much from the availability and cost of the capture technology but mostly from the cost of transporting the CO_2 through pipelines, and from local residents' resistance to underground storage. The population's concern about this technology has an impact on the length of the authorization cycle. The authorization cycle is long, due only in part to the administrative procedures in place. Pilot CCS siting programs and international cooperation, such as the collaboration with China and Korea on CCS, could provide Italy the opportunity to gain knowledge and a competitive advantage.
6. Large R&D efforts must be carried out to make all end-use sectors more energy- and resource efficient. This is particularly necessary in manufacturing and other energy-intensive sectors. For them, the priority is not only to decarbonize, but to modernize and innovate in a less carbon- and resource-intensive direction. Incremental innovation or wider use of ICT is not enough. This can be achieved largely through developing and deploying revolutionary enabling technologies such as electrometallurgy, advanced manufacturing, nanotechnologies, biotechnologies, advanced catalytic processes, superconductor and new materials. It is true that large research programs in these areas are costly from the perspective of an individual country. But lagging far behind in this type of research can be even more costly to the competitiveness of a country with a strong manufacturing base.

It can be argued that at present Italy is not fully exploiting its innovation and technology development and deployment potential. Italy closed the divide with other EU countries in environmental innovation between 1999 and 2004, in the number of environmental, renewable-energy, and CCS patents over total patenting by Italian inventors to the European Patent Office.[51]. However, since then, the country has lost some ground, and remains slightly under the EU28 average. After the economic crisis, the situation seems to have slightly worsened, with Italy falling further behind.[52] This is a general finding for Italy, which scores below the EU average both in terms of overall innovation and in terms of energy-related innovation.

In contrast, a number of non-technical challenges characterize the Italian energy transition. These include, as mentioned above, the acceptability of certain technologies and the management of related environmental risks, the siting of CCS facilities and renewable power plants, and consideration about changes in land use. Most of all, the challenge is the need to finance the energy transition by involving the private sector, and with appropriate financing schemes that would provide the necessary up-front capital to utilities, firms, and households so they can make the energy transition. All these hurdles need to be supported by

51 EPO is the European Patent Office, https://www.epo.org/index.html.

52 A different pattern characterizes the international cooperation of Italy in overall patenting. Data on co-patenting suggests that in Italy there is a higher percentage of patents with foreign inventors. This is however not specific to the energy sector, for which data is not available.

appropriate and effective policy interventions, as discussed below.

What policy support will need to be established to successfully achieve deep decarbonization?

In past decades, Italy adopted several policy instruments to support the deployment of RES (green certificates, feed-in tariffs, investment subsidies, tax deductions, etc) and to achieve energy-efficiency targets. This allowed important successes, increasing the share of renewables in Italy's primary and final energy consumption and improving overall energy efficiency.

However, following the DDPs illustrated in this report requires a much stronger effort in terms of technology development, and even more focused policy planning to achieve the deep decarbonization and modernization of the Italian energy system.

Italy needs to learn from its own best practices and past mistakes, and to improve policy implementation to contain the costs of the energy transition for producers, consumers, and the public sector., A high level of subsidies, such as those granted so far, is no longer necessary[53] to increase deployment of certain renewable technologies, or it should be targeted towards the technologies that present the greatest benefits but which are likely to encounter the most significant obstacles.

In a scenario characterized by higher electrification and higher penetration of variable renewables, it is crucial to invest in the overall strengthening and modernizing of the power grid. This would allow Italy to exploit the full potential of electric renewables, while improving service quality. It is therefore paramount to create a better framework to foster the necessary level of investment.

In light of the limited public financial budgets, another key requirement for the modernization of the Italian energy system is mobilizing private capital, and guaranteeing access to credit for firms and households. A clear regulatory context, streamlined administrative procedures,[54] and the intelligent use of public guarantee schemes, all framed by a stable long-term policy orientation (although admitting adjustments and corrections of the course adopted), would give investors a positive indication about the future for their returns on investments, limiting policy and regulatory risk.

Public-Private Partnership agreements (PPPs) should be highly encouraged because they would provide important private capital investment, the necessary public guarantees, as well as the private sector technology innovation and management expertise in project financing.

Appropriate normative frameworks for the operation of energy service companies (ESCOs) need to be put in place, to help fund the renovation of public and private buildings and condominiums so they attain better energy efficiency, or greater penetration of electric or thermal renewable energy sources.

A policy area in which Italy has lagged behind is the involvement of citizens and local communities in decision-making concerning large energy infrastructure in projects' early stages. As the Constitution grants local and regional governments a certain degree of autonomy over energy and environmental issues often conflicts

53 For instance, the generous Italian feed-in tariff scheme granting incentives over a period of 20 years for electricity generated by solar PV plants connected to the grid, known as "Conto Energia" was first introduced in 2005 and amended five times, Feed in tariffs have been granted also to electricity from wind and other sources. The overall burden of feed in tariffs for all renewables presently amounts to 12 billion €/year. Its magnitude has recently induced the Italian Government to re-modulate the subsidy regime, introducing in some cases retroactive changes.

54 An example of administrative burdens is given by the complexity of the registration procedure required for new renewable generating plants in the last version of the "Conto energia", which held back the amount of new capacity installed in most recent years.

between national interests and local interests arise, often paralyzing the realization of a project. A framework for involving citizens and local communities in decisions about large energy infrastructure programs is a key element to realize many renewable technologies and projects, and to develop technologies like CCS. Transparent stakeholder consultation processes at the local level, and participatory processes, should be more often implemented to facilitate public understanding of the actual risks, local costs, and benefits of a given energy technology or project.

A common critique of the Italian approach is that due to the lack of a national industrial development strategy, Italy has missed the opportunity to create its own renewable energy industry and has fed demand for systems and components produced elsewhere (China, Denmark, Germany, etc.).

Elaborating a national industrial development strategy, which includes as a core element the progressive decarbonization of the economy and the efficient use of all resources, would set a path for the transition of the Italian energy system. A coherent strategy would be based on strengthening the material and human research infrastructure, developing the technologies and products coherent with that perspective, and accelerating the innovation process to enhance the country's overall competitiveness.

One of the pillars of such a strategy should be a renewed effort at R&D at all levels of the chain, including higher education, training, and basic research. Development of new energy technologies and new enabling technologies or materials is necessary to develop less carbon- and resource-intensive production of goods and services, and to reduce the carbon footprint of consumption. Although Italy can certainly benefit from spillovers of global research activities, it could do more (either alone or through international research cooperation) in the areas of technology critical to a low-carbon transition (CCS, offshore wind for deep water applications, energy efficiency, energy storage technologies, etc.).

A strong government commitment and enabling policies are desirable to complement private funding in those stages of research where it is sub- optimal. After years of government budget cuts, in Italy, public research spending needs to return to levels closer to EU averages.

Appendix

The Energy system model TIMES-Italy

The Computable General Equilibrium models: GDyn-E and ICES.

The Energy system model TIMES-Italy

The Integrated MARKAL-EFOM System (TIMES) is an evolved version of the MARKAL modelling kit developed within a cooperative multinational project over 20 years by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA).

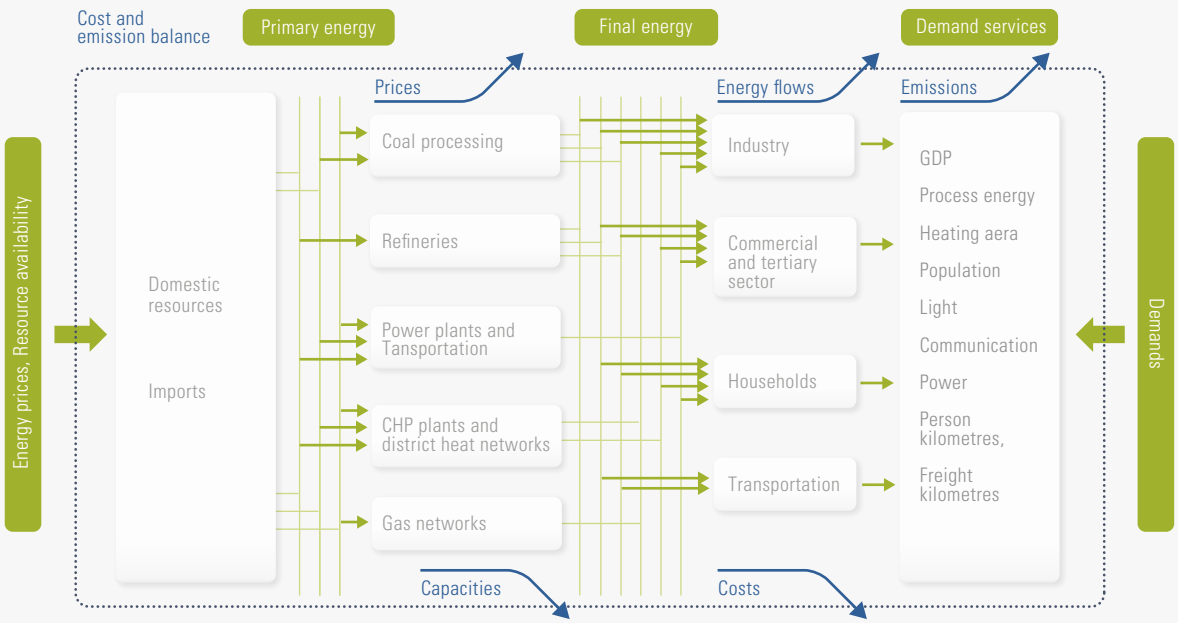
The TIMES-Italy is a partial equilibrium model of the Italian energy system developed by ENEA, as extracted region from Western Europe of the global model ETSAP-TIAM (TIMES Integrated Assessment Model).

TIMES-Italy is a bottom-up model of intertemporal optimization, which minimizes total cost for the energy system of meeting a given demand, subject to environmental and technological or policy constraints. The equilibrium solution is computed using Linear Programming techniques. The objective function is to minimize the global cost (more accurately at minimum loss of surplus) necessary to supply a given amount of energy services. In TIMES-Italy the quantities and prices of the various commodities are in equilibrium, i.e in each time period they are such that the suppliers produce exactly the quantities demanded by the consumers. This equilibrium has the property that the total surplus is maximized.

The base year of the model is 2006 and the time horizon covered is up to 2060. In addition, 12 time divisions (time slices) are considered within a year, for the power system (4 seasons, night and day and peak).

In addition to refinery and power sectors, TIMES-Italy considers 5 end-use sectors (agriculture, industry, residential, tertiary, transport) for a total of 43 energy service demands. In

Figure 33. Overview of the TIMES model



Source: Remme U., 2007

particular TIMES-Italy has an industry structure characterized by the explicit description of main production processes for the 5 energy-intensive industrial branches and All Other industries branch (Figure 33).

The main input data required from the TIMES-Italy model are: demand drivers (population, GDP, family units, sector GDP, etc); demand elasticities to the drivers and to their own prices; fuel import prices; technical and economic characteristic parameters of the various technological options and discount rates. Some energy services demand can be exogenous. Energy policies and / or energy and environmental constraints can be represented in the model. Multi-stepped supply curves are easily modeled in TIMES-Italy, each step representing a certain potential of the resource available at a particular cost. For each run, TIMES simultaneously computes: Energy produced, consumed; Energy and commodities prices; Technology adoption and abandonment; Emissions; Emission prices; Energy and material flows; Demands for energy services.

The model is used to explore the uncertainties of the energy system evolution under certain exogenous assumptions and to evaluate the effectiveness and the impacts of environmental and energy policies. The TIMES model is particularly suited to the exploration of possible energy futures based on contrasted scenarios. TIMES_Italy is formulated in the General Algebraic Modeling System (GAMS, Brooke et all. 1992) and solved with linear programming solvers

The Computable General Equilibrium models: GDyn-E and ICES

GDyn-E model (ENEA)

The GTAP model is a Computable General Equilibrium (CGE) model developed in the framework of the Global Trade Analysis Project (GTAP, Hertel 1997) coordinated by the Purdue University. The GTAP consortium elaborates and periodically revise also the GTAP Database, with a regional disaggregation of 134 regions defined as aggregates of 244 countries using the GTAP standard country list. The sector disaggregation considers 57 sectors. GTAP agricultural and food processing sectors are defined using the the Central Product Classification (CPC). The other GTAP sectors are defined by reference to the International Standard Industry Classification (ISIC).

An improved version of GDyn-E model (Golub, 2013), developed jointly by ENEA, the Department of Economics of Roma III University and the National Institute of Agricultural Economics (INEA) has been employed in this analysis (Antimiani et al. 2013). Relative to the standard GDyn-E database and model, several changes have been introduced, for example in sectoral substitution elasticities in the different energy nests, technological progress variables, equity representation and procedure to calibrate CO_2 emissions. The model has been extensively used for evaluations in different public policies domains, for example relative to the impacts of unilateral decarbonization policies on international competitiveness (Antimiani et al., 2013), of different options for taxing emission trading permits (Costantini et al., 2013; Antimiani et al., 2015), and of negotiating and financing options in global climate agreements.

The GDyn-E model is a top-down dynamic, multiregion, multisector Computable General Equilibrium model obtained by merging the dynamic version of GTAP – GDyn (Ianchovichina, E.,Mc-

Dougall 2001) with the recently revised form of static GTAP-Energy model (Burniaux and Truong, 2002). The model uses a treatment of investment behavior and additional accounting relations to keep track of foreign ownership of capital (Ianchovichina, E.McDougall 2001). In the model's nested production function energy can substitute for capital in the capital-energy bundle (Golub, 2013; Antimiani et al. 2013). Successive layers of nesting account for the choice between different energy commodities (electricity, coal, oil gas, oil products). Other non-fossil energy sources (nuclear energy, renewables) are not represented in the model. GDyn-E uses the GTAP database (Walmsley, Anguiar, Narayanan, 2012) B, version 8.1, the GDyn Data Base and the latest satellite GTAP-E Data Base (CO_2 emissions).

The model is solved as a system of simultaneous nonlinear equations via linearized representation, in different time steps. This allows a recursive solution procedure, a feature that allows easy implementation of dynamics into any static Applied General Equilibrium model without imposing limitations on the model's size.

ICES model (FEEM)

ICES (Inter-temporal Computable Equilibrium System) is a top-down recursive-dynamic, multi-sector and multi-region computable general equilibrium (CGE) model developed by Fondazione Eni Enrico Mattei based on the GTAP 8 database (Hertel, 1997; Narayanan et al. 2012) and the GTAP-E model (Burniaux and Truong, 2002).

ICES simulation period is 2007-2050 with 2007 as calibration year. Compared to the standard GTAP database and model, in addition to the dynamics in capital stock, it includes an enhanced portfolio for electricity generation, including renewable energy. Different versions of the ICES model have been extensively used in past exercises to economically assess climate change policies and impacts for different climatic scenarios and regional aggregations (see e.g. Bosello and Zhang, 2006; Bosello et al., 2006, 2007, 2008, 2014; Eboli et. al 2010; Parrado and De Cian, 2013).

The electricity sector in the GTAP database has been extended to consider different sources of renewable energy such as hydropower, solar, wind and biomass, using data from the Extended Energy Balances (both OECD and Non-OECD countries) from International Energy Agency (IEA, 2010), OECD/IEA (2005), and EC (2008). In addition, carbon, capture and storage are part of the technologies available for electricity generation. CCS is modelled, using information about the cost structure of CCS power plants from the IPCC (2005). The use of these technologies allow to reduce carbon emissions in electricity generation by around 90% on average, therefore reducing the burden of mitigation efforts.

Common features between the two models

Economic structure

On the supply side, industries are modelled through a cost-minimizing representative firm, which takes prices as given. The production functions are specified via a series of nested CES functions. Domestic and foreign inputs are not perfect substitutes, according to the so-called "Armington" assumption. Final output of sectors is a function of a technology, aggregate value added-energy composite, and other intermediate inputs. Aggregate value added-energy output is produced using primary factors (land, labor, natural resources, and a capital-energy composite, KE), following GTAP-E, considering inter-fuel substitution across an extended energy portfolio including renewable and clean energies. The capital-energy composite is produced by combining capital and energy. The Energy nest compounds Electricity with Non-Electric energy. On the demand side, a representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labor, capital). Capital and labor are perfectly mobile domestically but immobile internationally. Land and natural resources, on the

other hand, are industry-specific. Income is used to finance three classes of expenditure: aggregate household consumption, public consumption and savings. The expenditure shares are generally fixed, which amounts to saying that the top-level utility function has a Cobb-Douglas specification.

Recursive dynamics: Capital and debt accumulation

The two models generate a sequence of static equilibria under myopic expectations linked by capital and international debt accumulation. Growth is driven by changes in primary resources (capital, labor, land and natural resources). Dynamics are endogenous for capital and exogenous for other primary factors. Capital accumulation is the outcome of the interaction of: i) investment allocation between regions, and ii) debt accumulation. Savings are pooled by a world bank and allocated as regional investments.

CO_2 emissions

As in GTAP-E, the two models use average emission coefficients for each fossil fuel (Coal, Oil, Gas and Oil products) which are constant across sectors and regions of the world economy (Truong and Lee, 2003). Only CO_2 emissions from the combustion or use of fossil fuels are considered during the production process of a commodity or final consumption by households.

Macroeconomic analyses

Both models compute the impacts on macroeconomic variables, such as change in GDP, prices, import, export, consumption and production and evaluates changes in Welfare, cost of emission reductions in terms of carbon tax and energy commodities demand. They also include changes in foreign and domestic wealth and growth rates in capital.

Both models are apt to perform long term environmental-energy policy assessment since they can be used to determine how changes in policy, technology, population and factor endowments can affect the path of economies over time. They are particularly well suited for analyzing the impacts of long-term energy and climate policies.

Table 9 – Industry classification in ICES and GDyn-E of the five aggregates defined for comparing results across models.

Macro Sector	ICES (15 sectors)	GDyn-E (25 sectors)	GTAP sector
Agriculture	Agriculture	Agriculture;	Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts Oil seeds; Sugar cane, sugar beet; Plant-based fibers Crops nec; Bovine cattle, sheep and goats, horses; Animal products nec; Raw milk; Wool, silk-worm cocoons; fishing; forestry
Energy	Coal, Oil, Gas, NuclearFuel, Oil_Pcts, Electricity_Nuclear, Electricity_Renewables, Electricity _CCS, Electricity _Fossil Fuels	Coal; Oil; Gas; Oil_pcts; electricity	Coal; Oil; Gas; Oil_pcts; electricity
Energy intensive industries	Energy intensive industries	Mining; chem_petroc; non_MetMin; iron_steel; non_FerMetal	Chemical, rubber, plastic products; mineral products; ferrous metals; metals nec; minerals nec
Other industries	Other industries	Fishing, Forestry, Food_tob, transeqp, machinery, oth_Manuf, paper, wood; construct, textile	Forestry; Fishing; Bovine meat products; Meat products nec; Vegetable oils and fats; Dairy products; Processed rice; Sugar; Food products nec; Beverages and tobacco products; Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Metal products ; Motor vehicles and parts; Transport equipment nec; Electronic equipment; Machinery and equipment nec; Manufactures nec
Services	Market Services Public Services	Services	Water; Construction ; Trade; Communication; Financial services nec; Insurance; Business services nec; Recreational and other services; Public Administration, Defense, Education, Health Dwellings
Transport	Transport	Transport nec; Water transport; Air transport	Transport nec; Water transport; Air transport

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Standardized DDPP graphics for Italy scenarios

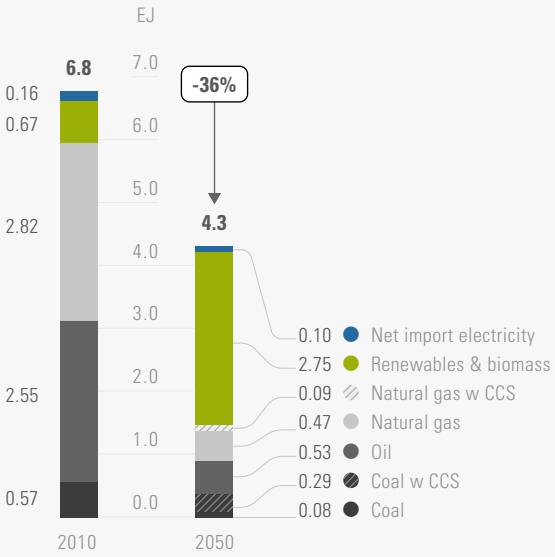
IT – CCS + Renewables

IT - Energy Efficiency

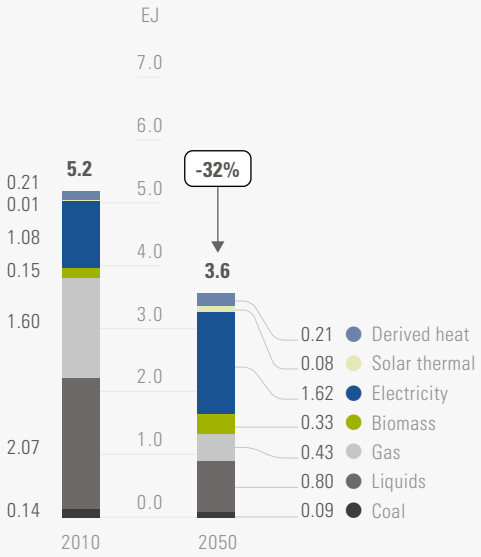
IT - Demand Reduction

IT - CCS + Renewables

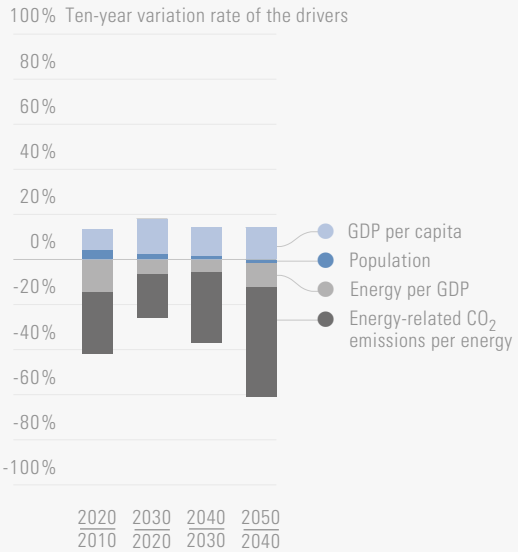
Energy Pathways, Primary Energy by source



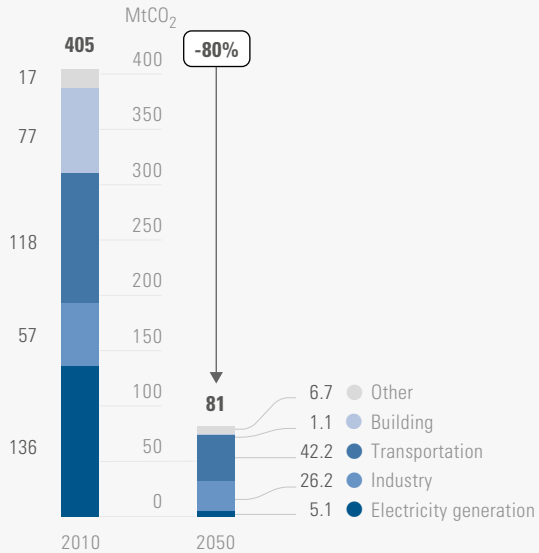
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector

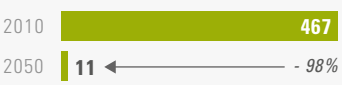


The Pillars of Decarbonization

Energy efficiency

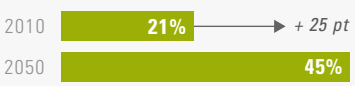
Energy intensity of GDP, MJ/$

Decarbonization of electricity



Electricity emissions intensity, gCO_2/kWh

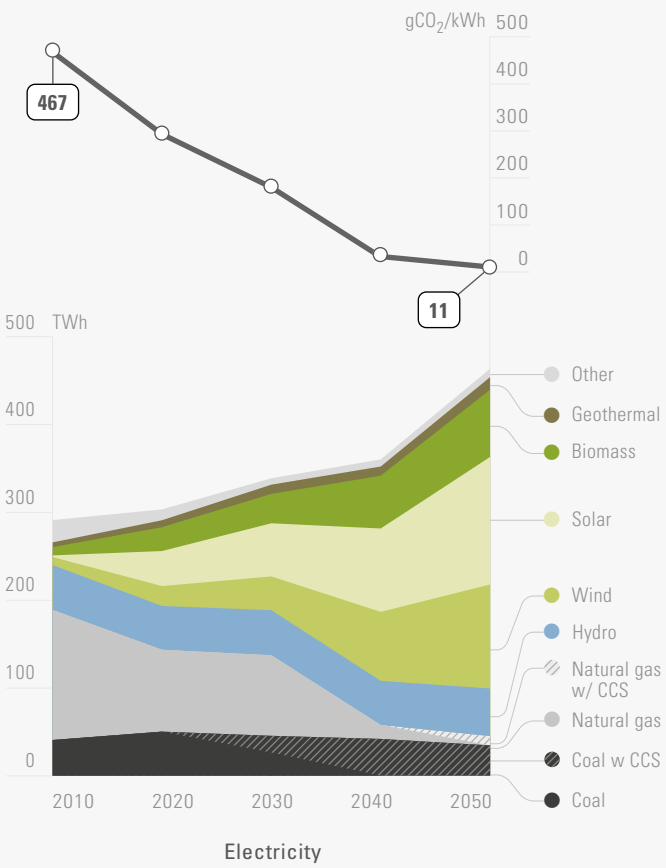
Electrification of end-uses



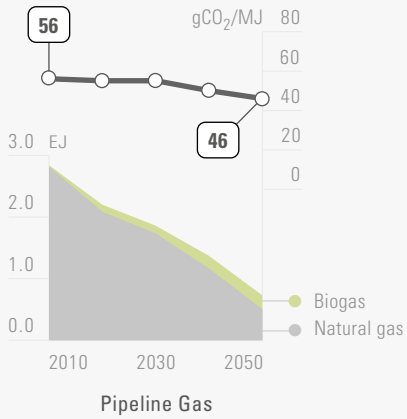
Share of electricity in total final energy, %

Carbon intensity

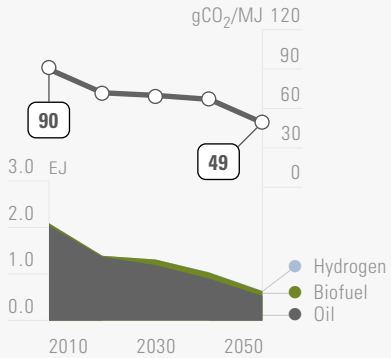
Energy Supply Pathways, by Resource



Electricity

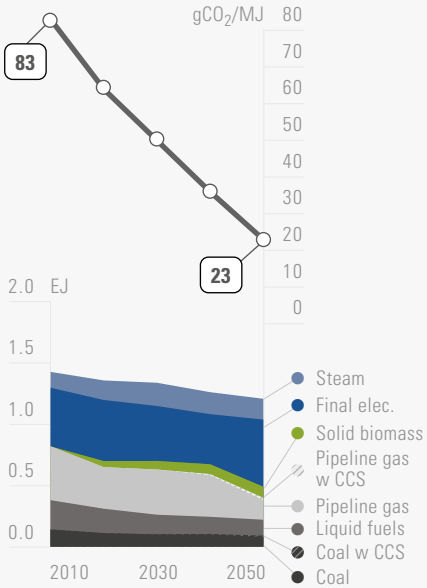


Pipeline Gas

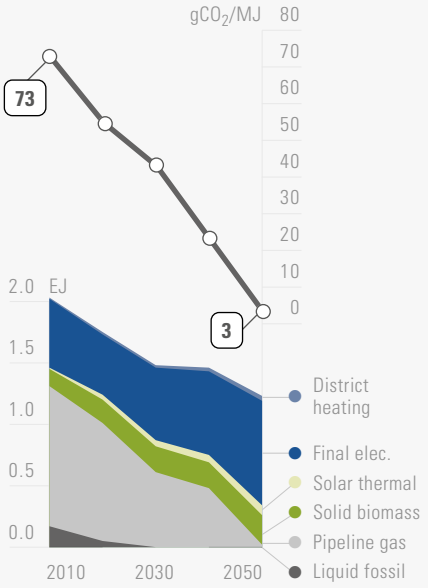


Liquid Fuels

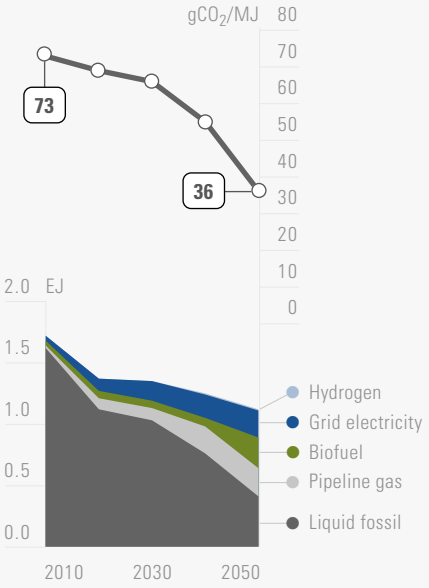
Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry



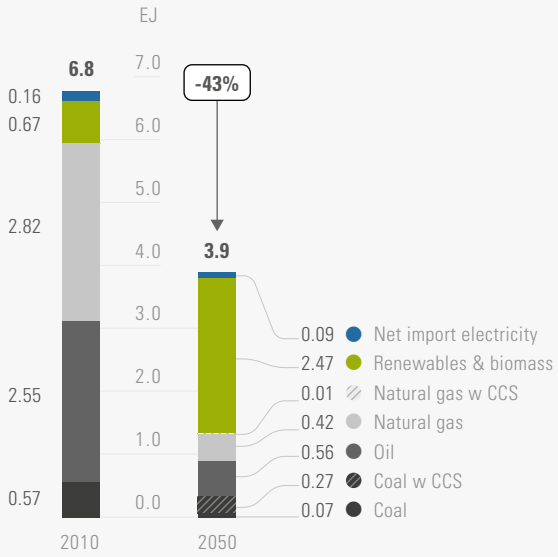
Buildings



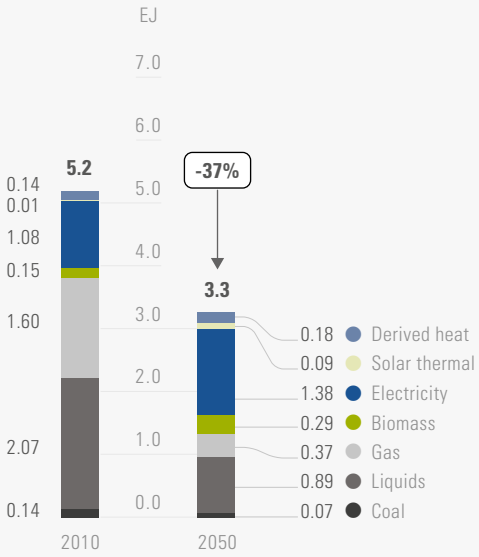
Transportation

IT - Energy Efficiency

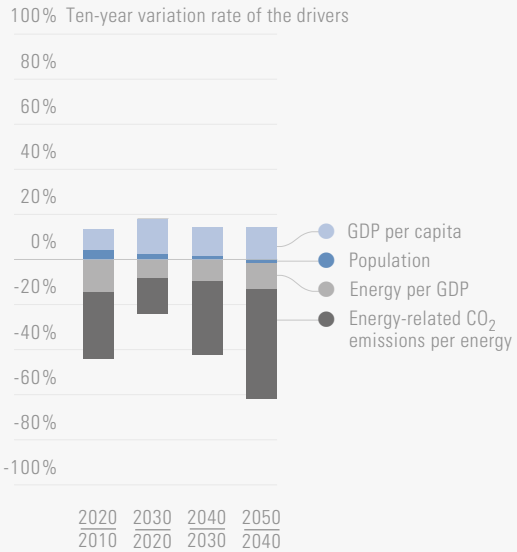
Energy Pathways, Primary Energy by source



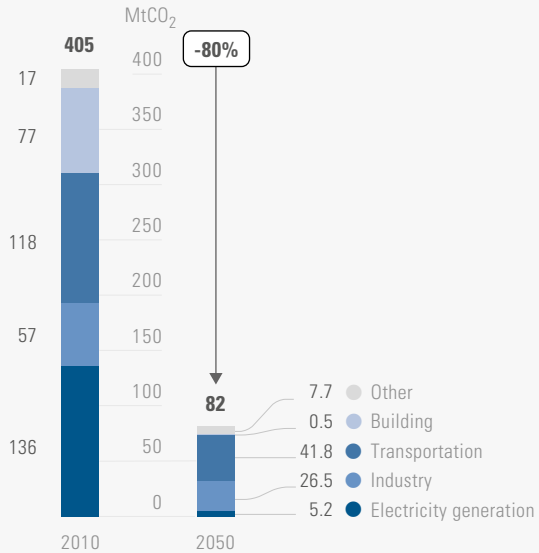
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



The Pillars of Decarbonization

Energy efficiency

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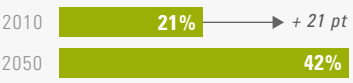
Decarbonization of electricity

Electricity emissions intensity, gCO_2/kWh

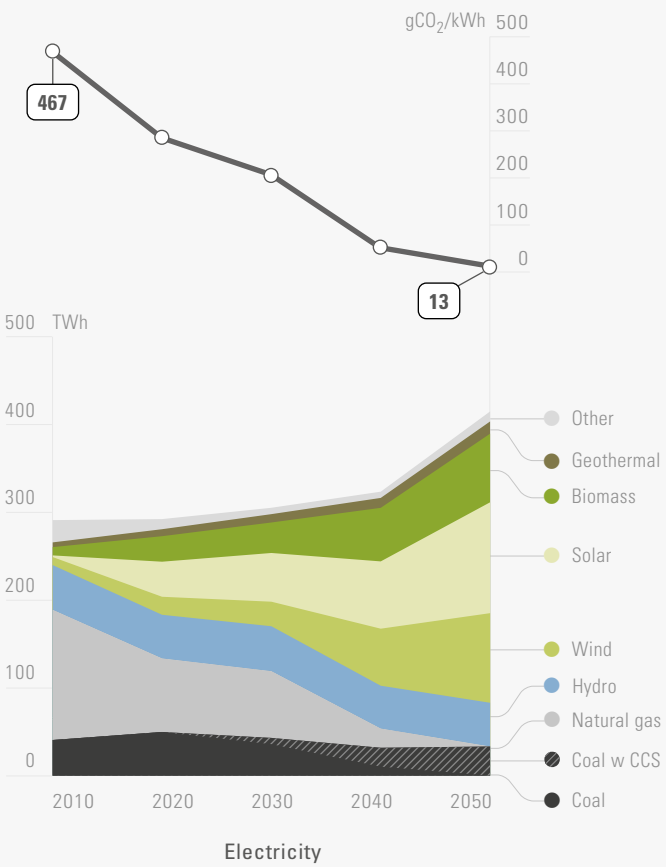
Electrification of end-uses



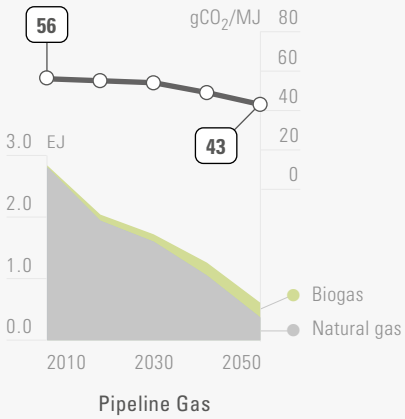
Share of electricity in total final energy, %

Carbon intensity

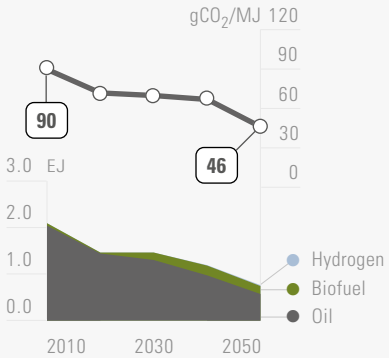
Energy Supply Pathways, by Resource



Electricity

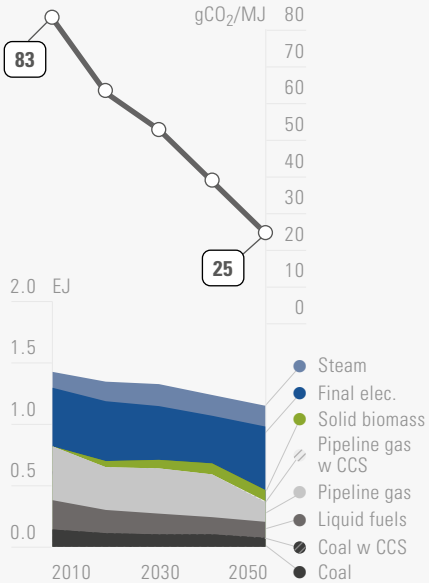


Pipeline Gas

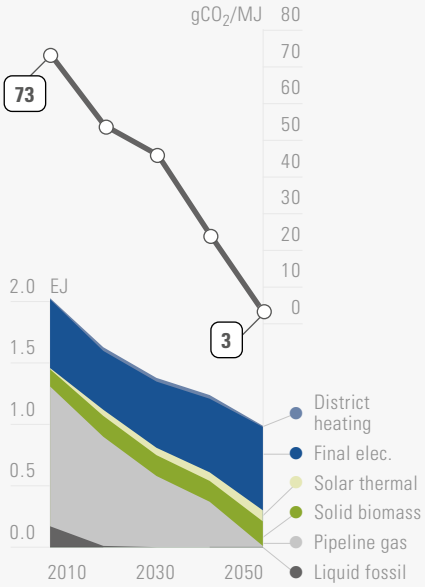


Liquid Fuels

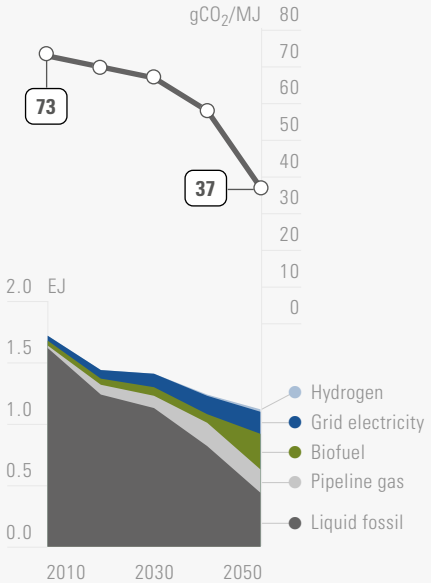
Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry



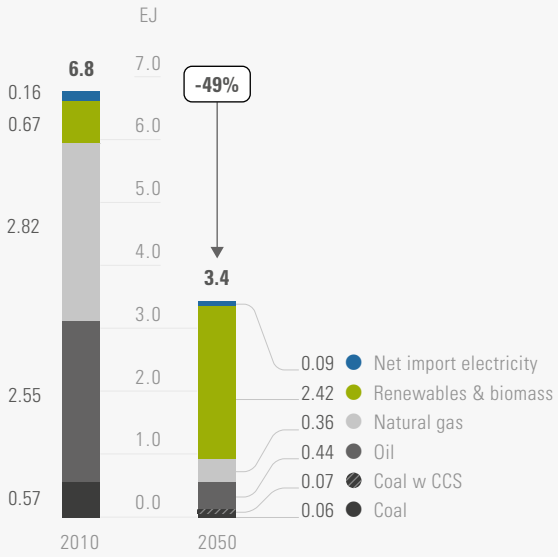
Buildings



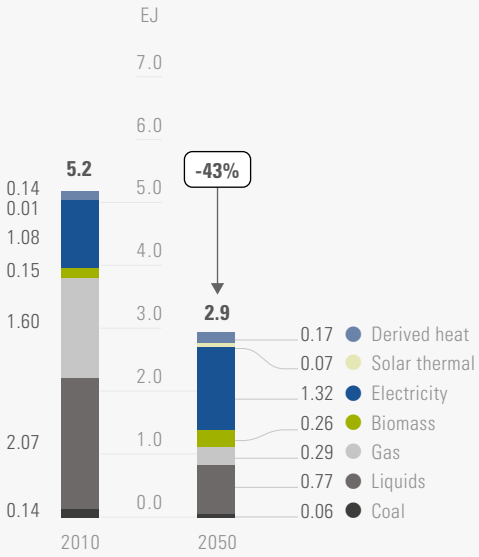
Transportation

IT - Demand Reduction

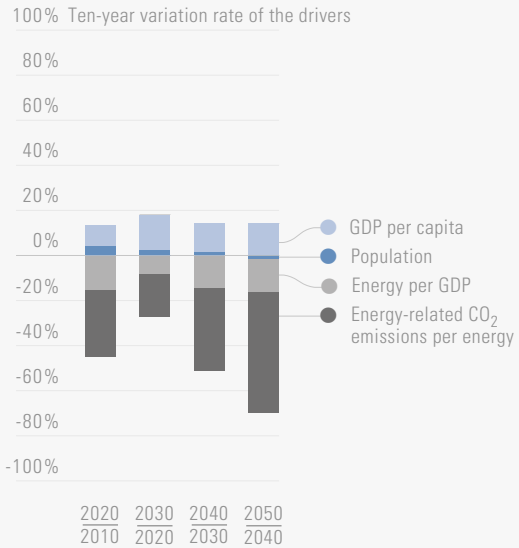
Energy Pathways, Primary Energy by source



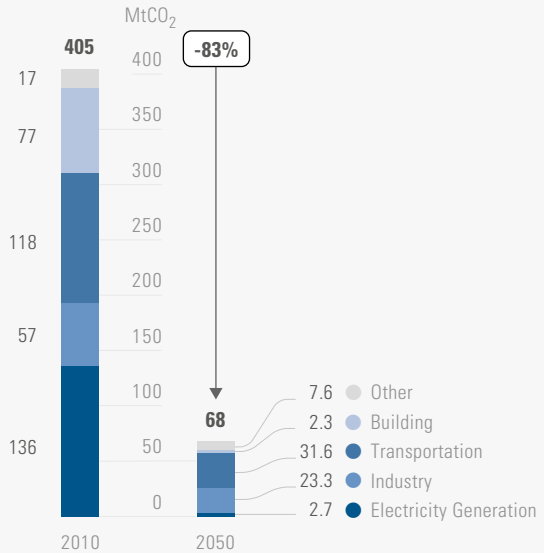
Energy Pathways, Final Energy by source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



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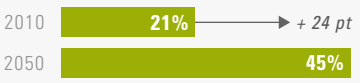
Decarbonization of electricity

Electricity emissions intensity, gCO_2/kWh

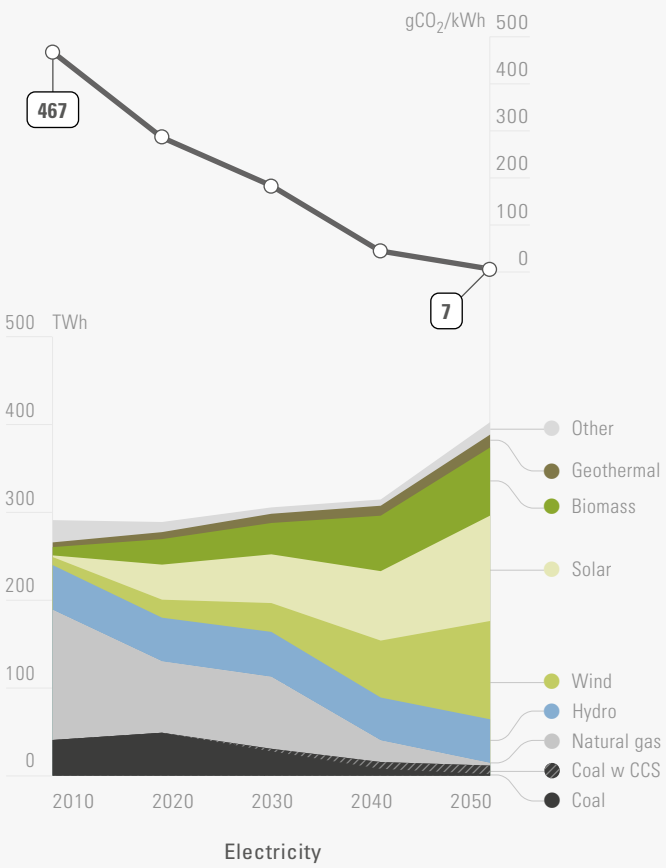
Electrification of end-uses



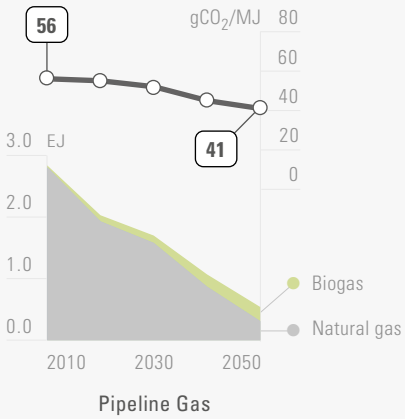
Share of electricity in total final energy, %

Carbon intensity

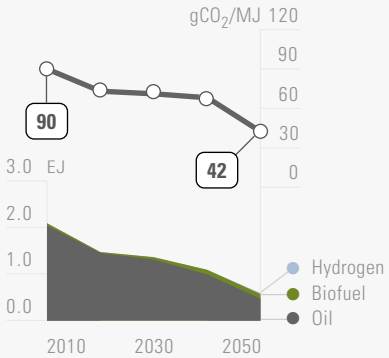
Energy Supply Pathways, by Resource



Electricity



Pipeline Gas



Liquid Fuels

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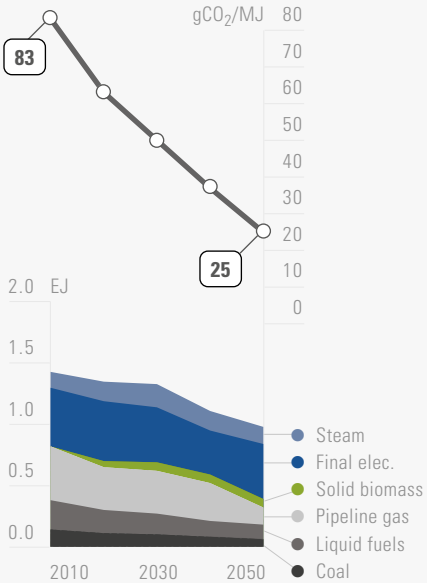
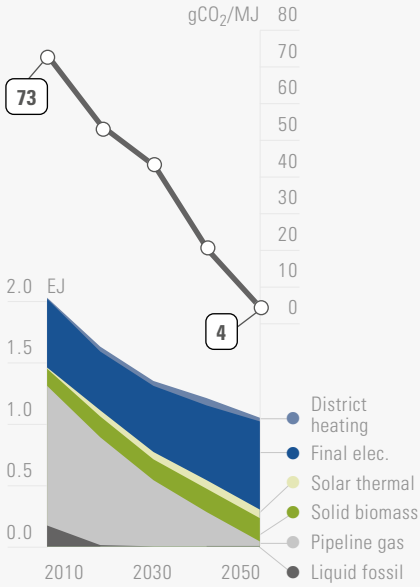
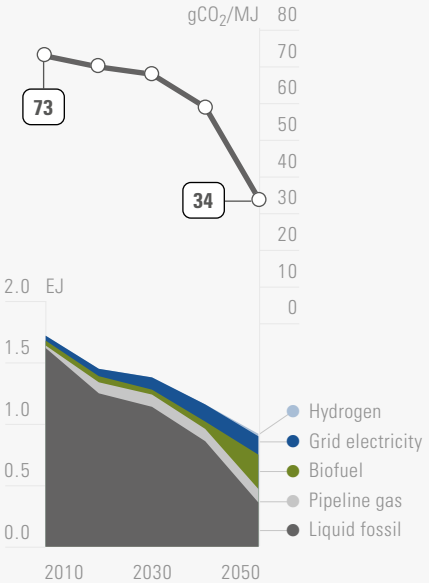


Industry



Buildings



Transportation