Electrify Italy

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Navigation icons

Back to Table of contents

Back to Last page visited

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TABLE OF CONTENTS

PREFACE

Francesco Profumo
Professor of Electrical Machines and Drives
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Energy is crucial for modern societies but a set of different issues are on the table and have to be addressed promptly.

Energy consumption is unevenly distributed around the world; total Final Energy Consumption (TFC) per capita ranges in the ration 1 to 145 for the population worldwide. A relatively small share of world population and areas consumes a large share of the world energy resources. This situation suggests that the idea of providing the same level of energy access to all the world population with the present prevalent paradigm is probably not viable. The allocation of a scarce resource is usually market-based, sharing the commodity based on the willingness (and ability) to pay, and eventually causes social tensions and energy poverty concerns. In 2016, 13% of the world population did not have access to electricity and 15% of the entire population in developed countries suffered from an energy poverty condition.

Fossil fuels also rise issues in terms of geopolitical security of energy, being large part of fossil fuels production concentrated in politically unstable and low developed countries while some developed ones, include the EU, show a significant level of energy dependency.

Furthermore, fossil fuels are very impacting from the point of view of GHG and air pollutant emissions – with drawbacks in terms of climate change and air/soil pollution and negative consequences on the life of biological systems (plants, animals and humans) – and will be exhausted in the mid/long term at this consumption rate. The potential further increase in energy consumption due to the expected additional contribution of the fast developing countries and of the less fast developing countries that need to recover the gap could lead to even more severe effects if a radical shift in paradigm is not undertaken in time.

All those issues prompt for an energy transition from the present fossil-based energy system to a new one based on renewables and efficient use of energy. The traditional fossil energy commodities are supposed to be integrated and, maybe in the long run, progressively substituted by other commodities both as energy vectors and in the final energy uses, and electricity may play a major role.

In a forward-looking vision up to 2050 for the national energy scenario, we can trace, based on the PoliTo/MIT/Enel Foundation study, some possible trajectories, in terms of the electrification of the country, considering a multi-focus perspective that integrates the penetration of renewables with the electrification potential of the residential, industrial and mobility sectors.

In particular, electricity generated from renewable sources looks a good candidate as alternative to fossil fuels, possibly in conjunction with hydrogen and biogas. Electricity can be directly generated from renewable energy sources (RES) and easily transferred over long distances while controlled with high efficiency. Most of the final energy uses based on electricity have higher efficiency than those based on fossil fuels.

The implementation of electricity as a mean for energy transition implies the so-called "electricity triangle": power generation from renewables, electricity as the main energy vector and electrification of final uses in all the sectors (buildings, industry and mobility). The electricity triangle is a general concept, and it applies to both main paradigms, i.e. centralised power generation and large-scale transmission systems (super grid) and distributed electricity production with small-scale distribution systems (smart grid).

The process of electrification of the energy sector may play a major role with cheap, self-produced electricity from distributed renewable sources that might cope with the energy needs of individuals and communities at more affordable prices. The general trend of the industrial countries toward "de-commoditization", in which the supply of an energy commodity is more and more substituted by the supply of a service (in which the amount and type of commodity is not anymore an issue for the final customers), provides an additional reason for selecting electricity as the energy commodity due to its flexibility in use and control. The exploitation of RES, locally available, can free or at least release the burden of energy dependency for many countries.

The implementation of an electricity-based energy transition is strictly intertwined with the extensive deployment of digital technologies to assure reliability, economic and operational energy efficiency. Digitalisation is a key aspect in the management of transmission and distribution networks and in the production section of the energy chain, under a perspective of a fast transition towards renewables. Digitalisation and electrification can lead to positive impacts from the point of view of an easier management of the energy systems and of their optimisation. The "internet-of-things" (IoT) will make it possible to connect the physical world (people, machines, materials, buildings, environment, etc.) to the information world (e.g. big data analytics), thus allowing to process data, providing analyses and foresights. Moreover, digitalisation could support energy demand response measures, like the shifting of heating and cooling loads and the optimal charging strategies for electric vehicles. Digitalisation could also impact on the social dimensions, nudging the habits of people and improving the quality of life in urban areas: this will allow the transformation of citizens from consumers to prosumers, enabling the so-called "energy communities".

The investigation of the possible pathway for an energy transition based on electrification in Italy up to 2050 and the joint effort undertaken by Politecnico di Torino, Massachusetts Institute of Technology and Enel Foundation is surely timely and able to set the stage for further analyses and discussions about the institutional, technological and regulatory framework needed for bringing our country in this new dimension.

In a forward-looking vision up to 2050 for the national energy scenario, we can trace, based on the PoliTo/MIT/Enel Foundation study, some possible trajectories, in terms of the electrification of the country, considering a multi-focus perspective that integrates the penetration of renewables with the electrification potential of the residential, industrial and mobility sectors. A 46% electrification of the three considered end-use sectors by 2050 is forecasted, coupled with an 86% penetration of renewable sources in the electricity generation mix, with solar playing a key role. Potential benefits can arise from the further electrification of the Italian energy system on energy, economic, environmental and social aspects. Indeed, the strong reduction of total final energy consumption (more than 40%), enabled by the higher efficiency of the electric technologies, allows reducing of almost 2/3 the CO_2 emissions by 2050, as well as greatly reducing the air pollutant emissions (approximately 70% reduction for both PM and NO_x). Italian economy can benefit from this electrification, which can help reducing of 70% the energy intensity. In parallel, from a social standpoint, electrification can unlock relevant savings in the healthcare (almost 800 Billion € cumulated savings by 2050) and can boost the energy affordability for Italian families.

FOREWORD

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The energy transition is a crucial challenge for humanity. The present energy paradigm is not sustainable, and we need to find new ways to satisfy the global energy needs in an equal, fair, and environmentally friendly way. The transition towards a sustainable energy system implies shifting from fossil fuels to renewable energy sources. This is already happening in electricity generation, and, through electrification of final energy uses, in transport, heating, cooking, as well as in industrial uses. This transition is environment-friendly, protecting our planet from pollution and climate change, and has significant benefits to the economy and the society.

This study, carried out jointly by Politecnico di Torino, Massachusetts Institute of Technology and Enel Foundation, aims to discuss possible pathways for an energy transition for Italy based on the electrification of the whole energy sector.

For this purpose, on the supply side we have considered the transition towards a massive exploitation of renewable energy sources for electricity production. On the demand side, we have studied the final energy uses and electrification potential of three crucial sectors: residential, industry, and transport. The analysis is carried out up to 2050, with two intermediate steps in 2022 and 2030. In particular, the sectorial electrification potential was investigated by means of developing and implementing ad hoc modelling techniques, able to consider the technical and economic characteristics of the currently available and the possible future development of electricity-based end use technologies. Consequently, the research developed multiple scenarios detailed in this document.

The outcome of our analysis shows that an energy transition based on electrification will bring Italy numerous benefits, which have been quantitatively assessed with an integrated multi-dimensional approach through a set of around 40 Key Performance Indicators, related to four different domains: energy, environmental, economic and societal.

The quantitative results have been compared with other national and international analyses and contrasted with the opinions of a set of key stakeholders about future energy scenarios and electrification. Altogether, we are confident to conclude that there is a general consensus and largely accepted evidences of a positive trend towards an electrified future for Italy, which will bring sizeable benefits to the environment, the economy, and the society.

We wish to thank the scientific advisory board, the research team of the project, and the experts who openly shared their views on this crucial topic for their valuable contributions.

IS COVID-19 CHANGING THE PICTURE?

COVID-19 is having significant impacts on Italian society and economy. These impacts are reflected in energy and electricity demand and prices.

Although this is an unquestionable fact, the nature and magnitude of the impacts are still uncertain even in the short term. Forecasts about how the Italian economy will perform in 2020 vary across experts and among national and international institutions, as well as over time. The most recent economic estimates at the time of publishing this book envisage a reduction of GDP in 2020 just below 10% with respect to 2019.

This shock will probably have the most significant impacts in the short term, while recovery is expected to take place in the longer term coinciding with the period considered by this study. The shape of the recovery is however very difficult to predict, also because econometric models capable of extrapolating behavioural patterns from the past do not apply in a totally new situation, as the one we are in. Yet, we asked ourselves if the electrification case made in this study would still apply in light of COVID-19 impacts, and concluded that it fundamentally will.

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) reported[1] a 7% reduction of primary energy

1. *https://www.enea.it/it/seguici/pubblicazioni/pdf-sistema-energetico-italiano/01-analisi-trimestrale-2020.pdf*

consumption in the first quarter of 2020 and a projection of more than a 10% reduction in the first two quarters, since the effects of the lockdown started to bite in the second half of March. These reductions are primarily for oil and gas resources, while renewables are estimated at the same level as 2019 and electricity imports have slightly increased.
In terms of final energy consumption, ENEA reports a reduction of 8% in gas and oil products and only 4.5% in electricity in the first quarter of 2020. There are serveral reasons for these trends. On the one hand, the lockdown strongly affected the private transport sector, which is still dominated by oil products. On the other hand, while electricity demand has gone down in the industrial and commercial sector, it has gone up in the residential sector. Moreover, it is important to remember that electricity enables a number of services, which proved fundamental in mitigating the effects of this emergency. These services include digital communication, which in turn enabled smart working and remote education, and entertainment technologies. Electricity, notwithstanding a significant demand reduction, emerges as being more resilient in situations like the COVID-19 emergency.
The reduction of electricity demand has, however, had an immediate effect on electricity markets. Higher marginal costs of thermal power generation have often pushed the latter out of the merit order, thus reducing its share in favour of renewables. This caused a reduction of day-ahead electricity prices by about 10 €/MWh (-24%) on average in the third week of March 2020 with respect to the third week of February 2020. This confirms that higher penetration of renewables tends to reduce generation cost, although it requires additional investments to adopt suitable measures to guarantee system stability, including not only an adequate amount of flexible generation capacity, but also smart grids, energy storage and demand response resources. A forward-looking regulation is fundamental to assure timely and cost-effective implementation of these measures.
Notably, the increased share of renewables in final energy consumption so far this year, supported by electricity, pushed CO_2 emissions down in a percentage that is higher than the reduction of energy consumption, since the corresponding reduction in generation was concentrated on fossil fuels.
All of the above suggest that the case for electrification made in this study therefore remains fundamentally valid. Of course, much will depend on what measures will be implemented to support the rebound of the economy. As pointed out by a recent working paper by the Oxford University[2], stimulus policies directing resources towards investments in renewables and clean energy infrastructure are attractive both in the short and in the long-term. Such policies generate more jobs in the short run, boosting spending and increasing short-run GDP multipliers (which are derived from expanding demand). In the longer run, they require less effort for operation and maintenance, freeing up resources as the economy returns to full capacity thereby offering higher long-run multipliers (which are derived from expanding supply). Put simply, green investment policies have the potential to both support quick, short-term recovery and to sustain prosperity in the years to come. Therefore, there seems to be a way to turn this terrible emergency into a valuable opportunity for the economy, the environment, and the society at large. The process of electrification envisaged by this study is perfectly in line with this vision.

The outcome of our analysis shows that an energy transition based on electrification will bring Italy numerous benefits, which have been quantitatively assessed with an integrated multi-dimensional approach through a set of around 40 Key Performance Indicators, related to four different domains: energy, environmental, economic and social.

We humbly hope that this work might provide a positive scientific contribution to the debate about the energy transition and the approaches to implement it in an effective and beneficial way in Italy. We also hope that this study can serve as a basis for a fruitful discussion with all the stakeholders, including academics, industry and policy makers, aimed at tackling these important challenges and to identify actionable solutions for the implementation of future electrification scenarios.

2. Hepburn, O'Callaghan, Stern, Stiglitz and Zenghelis, "Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?" Oxford Smith School of Enterprise and the Environment | Working Paper No. 20-02.

EXECUTIVE SUMMARY

This study explores a possible pathway to implement a new energy paradigm in Italy based on electrification.
The objectives are:

- **To build** a forward-looking vision of possible scenarios at 2022, 2030 and 2050 by integrating a multi-focus perspective on the penetration of renewables and the electrification potential of the residential, industrial and transport sectors.
- **To estimate** the potential benefits of further electrification through the calculation of Key Performance Indicators in four different areas: energy, economy, environment and society.

The study shows how the electricity triangle, a paradigm based on clean generation by renewable sources, electrification of final uses, and electricity exchange through efficient smart grids, closes the loop of clean energy and efficient consumption. This leads to improvements in energy, environment, economy and social performances, and boosts the share of renewables in final consumption.

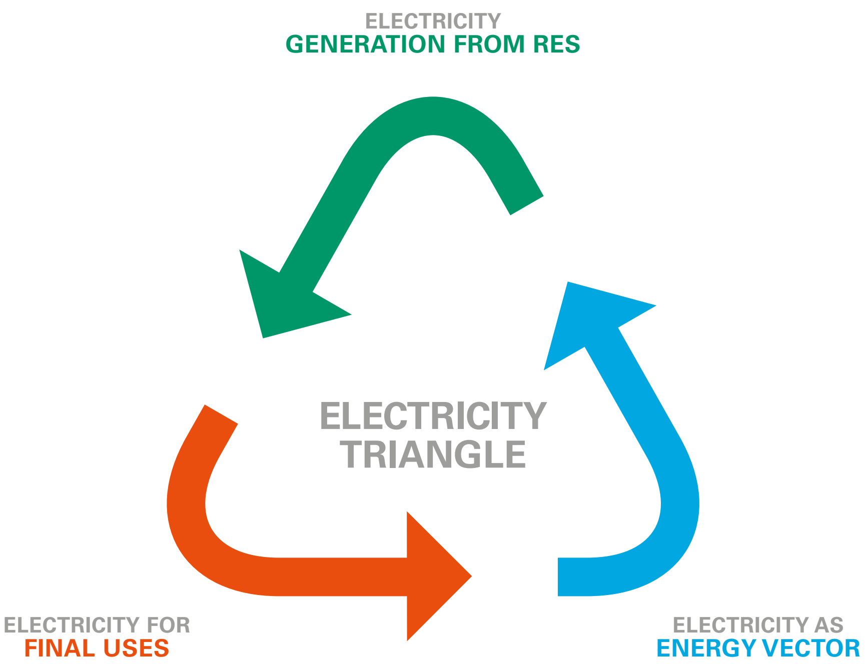

Figure 1
Electricity triangle.

Three key findings of the research are:

1. Electrification can effectively contribute to decarbonization

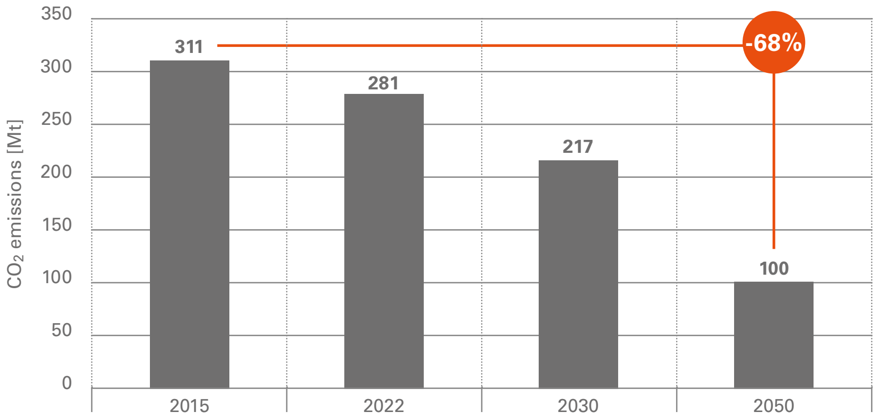

Figure 2
Total reduction of CO_2 emissions from residential, industrial and transport sectors.

2. Electrification can unlock relevant savings in the healthcare

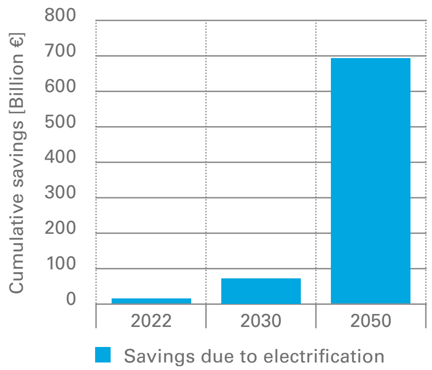

Figure 3
Cumulated cost savings (healthcare, productivity, life).

3. Electrification can increase the affordability of energy for Italian families

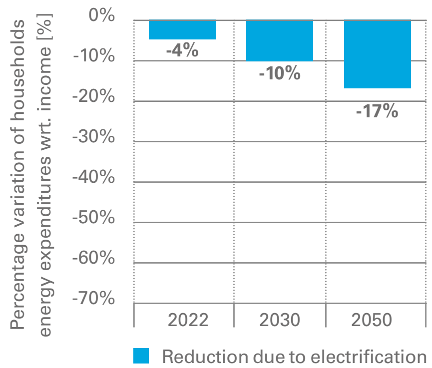

Figure 4
Households energy expenditures with respect to the income.

This study will serve as a basis to discuss the challenges related to the implementation of electrification scenarios with academics and other stakeholders.

ELECTRIFY ITALY / SUMMARY

Electrify Italy

Possible electrification pathways in Italy up to 2050 and related benefits

BASELINE 2015

20.8%
ELECTRIFICATION
share of electricity in total final consumption

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INDUSTRY
2015: **39%**
2050: **42%**

TRANSPORT
2015: **3%**
2050: **41%**

RESIDENTIAL
2015: **15%**
2050: **53%**

ELECTRIFICATION
Electrification will increase up to almost half of final consumption

2015: **17%**
2022: **19%**
2030: **24%**
2050: **46%**

Share of electricity in total final energy consumption of the three sectors studied

RENEWABLE PENETRATION
Renewable share in electricity supply will overcome 85%

2022	2030	2050
48%	59%	85.6%

Share of total electricity supply produced by renewable

DECARBONIZATION
CO_2 emissions will be slashed by more than half

CO_2 emissions
% variation vs. 2015

	2022	2030	2050
Emissions	281 mt	217 mt	100 mt
Variation	-10%	-30%	-68%

PUBLIC HEALTH SAVINGS
Total costs saved due to better air quality reach 692 bn€

2022	2030	2050
16 bn€	72 bn€	692 bn€

Cumulated savings due to reduction of healthcare expenditures, recovery of productivity, avoidance of premature deaths (billion €)

AFFORDABILITY FOR FAMILIES
Weight of energy bill for families will be reduced by 17%

2022	2030	2050
-4%	-10%	-17%

Household energy expenditures over the income
(% reduction due to electrification only)

ENERGY EFFICIENCY
Primary energy consumption will steadily decrease

2022	2030	2050
-10.2%	-18.9%	-42%

Primary energy consumption % variation vs. 2015

Source: Electrify Italy, ITELEC 2050 scenario

1. MAIN HIGHLIGHTS OF THE STUDY

In a relatively prudent scenario, ***electrification in Italy will reach 46% of final energy uses in residential buildings, industry and transport in 2050.*** This further electrification of the Italian economy, accompanied by a consolidation of renewables, can represent a viable, effective solution to creating a more sustainable energy system:

- Strong reduction of total final energy consumption (-42%).
- Reduction of CO_2 emissions by 68%.
- Reduction of 76% of PM10 emissions and of 69% of NO_x emissions, generating cumulated savings of 692 Billion € by 2050, due to the reduction of healthcare expenditure, recovery of lost productivity and avoidance of premature deaths.
- Boosting energy affordability for Italian families, as the share of income that a family will need to devote to energy expenditures will decrease by up to 17% in 2050.

RES can economically achieve a penetration in excess of 85% in the generation mix, even with relatively low CO_2 prices:

- Solar will play a key role, reaching a penetration in excess of 60%.
- Storage will play an increasingly important role over time, with a projected installed capacity of about 112 GW, out of which 106 GW will be captured by electrochemical batteries.

The residential building and transport sectors have the largest electrification growth potentials, whilst the industrial sector can improve efficiency through electrification:

- The residential building sector has the potential to become the most electrified sector in Italy (up to 53%, from an initial 15%).
- Transport has the potential to grow from 3% to 41%.
- The industrial sector, already highly electrified, can further increase electrification from 39% to 42%.

Consumers making environmentally-friendly choices can be incentivized by appropriate policy measures, which can lower the barriers hindering a large-scale adoption of electrical technologies, and thus help the electrification process. The economics, which, in some cases, still unduly favour traditional technologies, can be significantly rebalanced, for example by:

- Properly pricing PM and CO_2 emissions.
- Revising regulated price components which overburden electricity with taxes and levies, and extending the non-progressive electric tariff for heat pumps.

SECTOR HIGHLIGHTS

Residential buildings:

- The penetration of heat pumps for space and water heating in the residential sector can grow 27 and 7 times respectively, reaching about 21 million units each.
- Due to the combined effect of the increase in both AC installations and the number of hot days, the demand for air conditioning will grow by 81% in 2050, with an additional electricity demand of 21 TWh. The effect of hot days alone will increase the AC energy demand by more than 12%, equal to more than 5 TWh.

Industry:

- Further electrification potential can be captured by progressively introducing low and low-to-medium temperature heat pumps. This corresponds to 3.1 TWh additional yearly electricity demand, equivalent to 76% of the low and low-to-medium temperature heat demand in 2050. On the contrary, the penetration of medium- and high-temperature electrical appliances is unlikely to happen according to the current outlook.
- Demand response and flexibility markets could change the economics of electrical appliances not yet convenient at current electricity-to-gas price ratios and conversion efficiencies. Flexibility requirements in the power sector are among the factors that could support the penetration of low-to-medium and medium temperature electrical appliances.

Transport:

- The share of electric vehicles in Italy will rapidly increase in the coming decades, up to 83% of the total fleet in 2050. The two main factors driving this are the reduction in the total cost of ownership and the likely increase in the environmental restrictions in urban areas.
- Additional electrification opportunities will come from public transport, as some Italian public transport operators are already starting to increase the share of electric vehicles in their fleet. For example, Milan has already committed to transform its fleet by 2030, with 1,200 extra electric buses.
- Moreover, long-range coaches have the potential to further expand this market driven by new models with ranges up to 400 km as well as the reduction of the cost of batteries. The report considers a penetration of 20% of electric coaches in Italy by 2050.

2. RATIONALE AND OBJECTIVES

This study originates from the observation of the limits of the current fossil fuel based global energy paradigm, especially those hindering sustainable development.
Today's global energy system predominantly relies on fossil fuels, which account for 81% of total primary energy supply.
Consequently, the energy sector is responsible for almost two-thirds (61%) of total CO_2 emissions, making it a major factor of anthropogenic climate change[1].
Moreover, it is responsible for the majority of air pollutants at a global level (>99% for both sulphur dioxide and nitrogen oxides, and about 85% for particulate matter 2.5)[2]. The only exception is ammonia, for which agriculture, solvents, and waste are the largest emitters.
Air pollution has a strong impact on public health. It is estimated that 7.3 million deaths every year are attributable to indoor and outdoor air pollution, and that 91% of the world's population live in areas in which air pollution exceeds the WHO[3] (World Health Organization) recommended limits.
According to VIIAS study[4] in Italy in 2010, around 35,000 premature deaths may have been related to exposure to air pollutants (particulate matter, nitrogen oxides and ozone).
Even with huge advances in new technology for energy provision, our current global energy systems are not capable of providing enough energy at an affordable price. Today, about 1 billion people still do not have access to electricity, mainly due to a lack of infrastructure or affordability issues. Even in otherwise developed countries, 15% of the population (about 200 million) are suffering from energy poverty[5].
Moreover, Total Final Energy Consumption (TFC) is quite unevenly distributed. In 2016, the average per capita TFC was 53.9 GJ/person, ranging from 1.9 GJ/ person in South Sudan to 289.9 GJ/ person in Qatar. The Gini[6] index of per capita TFC at a global scale is at 0.534, showing significant inequality in energy consumption. As a comparison, the same indicator is 0.222 between the 28 countries of the European Union, showing a much more even distribution.
Another major issue facing global energy production is the availability of resources. Fossil resources are concentrated in a few countries, many of which suffer from high political instability and low overall development. At the same time, several world areas show a significant level of energy dependency. In 2016 it was equal to 53.6% for the European Union and to 77.5% for Italy[7].
It is clear that ***the current energy paradigm is not sustainable, and a transition to a new system capable of overcoming the limits of the current one is necessary.***
This study aims to explore a new energy paradigm in Italy, a possible pathway to implementation, and to estimate the potential benefits of this transition.
Electrification can be a key tool for the transition towards a sustainable energy system. Electrification closes the loop of clean energy and efficient consumption; improves energy, environment, economy and social performances; boosts the share of renewables in final consumption.
This study shows how the energy triangle, a paradigm based on clean generation by renewables sources, electrification of final uses, and electricity exchange through efficient smart grids, can bring remarkable benefits. The positive impacts of the energy triangle include decarbonization, reduction of pollution and an increase in electricity affordability, thus representing a viable solution to the above-mentioned issues.

The objectives of this study are:

- To discuss electrification as a major option for implementing energy transition in Italy, starting from the present status of electrification and building a forward-looking vision of possible scenarios at 2022, 2030 and 2050.
- To integrate a multi-focus perspective, with analysis of demand and supply, to study the potential electrification of three main sectors (residential, industrial and transport) and the possible renewable penetration for Italy up to 2050.
- To estimate the potential benefits of further electrification of the Italian energy system through the calculation of Key Performance Indicators in four different areas: energy, economy, environment and society.

3. METHODOLOGY AND STRUCTURE

This work is based on the following elements:

- Review of the ***perspectives on electrification*** of the main energy players through interviews with sector experts.
- Analysis of the ***penetration of renewable*** energy sources in the energy supply.
- Assessment of three key ***demand sectors:*** residential buildings, industry and transport.
- Creation of a ***multisector scenario*** (ITELEC2050) composing the above analyses to represent a possible evolution of the Italian energy system up to 2050.
- ***KPI calculation*** to evaluate the potential benefits of this transition in four dimensions: energy, environment, economy and society.

PERSPECTIVES ON ELECTRIFICATION

The objective of this element is to identify the current perceptions of key

1. IPCC - Climate Change 2014: Synthesis Report; IEA Statistics, 2016 data; UN Environment Emissions Gap Reports, 2016 data; IPCC – Global Warming of 1.5°C, 2018

2. IEA, "Energy and Air Pollution. World Energy Outlook Special Report", IEA Publications, Paris, 2016

3. WHO - www.who.int/airpollution/en/

4. VIIAS, valutazione integrata dell'impatto ambientale e sanitario 2018

5. IEA energy access outlook 2017

6. The Gini index measures the extent to which the distribution of a variable deviates from a perfectly equal distribution. A Gini index of zero represents perfectly equal distribution and 1, perfect unequal distribution.

7. Eurostat, "Energy Statistical Database"

players in the energy sector on the transition of the Italian energy system. The main areas of interest are their perceptions on the expected impacts, benefits, barriers and concerns regarding the electrification process.
For this purpose, a sample of 16 representatives of the major players of the Italian energy sector were interviewed. The sample included experts from manufacturing companies, distribution system operators (DSOs), utilities, regulatory bodies and research institutions.
The main insights drawn from these interviews are as follows.
Interviewed players agree that the energy transition has already started, and electrification is key to this transition. Residential heating, transport and industry were identified as the main sectors in which the electrification process might provide the greatest contributions in terms of emission reduction and an increase in renewable energy use.

Main perceived benefits of the energy transition are:

- Energy efficiency increase, thanks to electric-powered technologies.
- An increase in renewable penetration.
- Subsequent decarbonization and creation of a sustainable system.
- Creation of new jobs connected to the birth of new industrial value chains.

The main perceived barriers are:

- Need for new customer propositions and to overcome some negative perceptions.
- High initial investment cost for technology development and substitution;
- Current high electricity-gas price ratio.
- Inertia of existing infrastructure.
- Lack of adequate regulation to enhance the recovery of the investments required by the transition.

ANALYSIS OF THE PENETRATION OF RENEWABLES

The assessment of renewable penetration in power generation is performed with a total cost optimization model. The GenX tool[8] is used for generation expansion planning (GEP). Three scenarios have been developed based on increasing CO_2 price levels: constant zero price, CO_2 price equal to IEA Current Policies scenario, and CO_2 price equal to IEA Sustainable Development scenario.

Key assumptions:

- Retirement of coal-fired power plants by 2025.
- No constraint on the potential expansion for gas, oil and solar power plants.
- Installed capacity for hydropower and geothermal is constant over time.
- Expansion of onshore and offshore wind power generation up to 20 GW and 1 GW respectively in 2050.
- Two types of bioenergy modelled: cogeneration units assumed without expansion potential; electricity-only production units assumed to have expansion potential.

8. GenX tool is a generation expansion planning tool developed by the MIT

ASSESSMENT OF THREE KEY DEMAND SECTORS: RESIDENTIAL BUILDINGS, INDUSTRY, AND TRANSPORT

Residential buildings

The detailed analysis is based on the minimization of the Global Cost for CO_{2eq} Avoided (GCCA) indicator[9]. GCCA allows for the identification of the optimal technology mix for carbon emissions reduction.
This model is applied to space heating and water heating of residential building stock. These uses represent 80% of total energy consumption from the residential sector. As non-residential buildings represent only 10% of Italian building stock[10] and they are already highly electrified (51%) due to high appliance density and high air conditioning demands, they are not included.
The evaluation of the electrification potential and of future possible technological trends is performed through the development of the "scenario FB[11]".
The analysis is performed based on reference buildings representative of the Italian building stock, according to different typologies (Single Family Houses, SFH, and Multi-Family Houses, MFH) and periods of construction ("before 1980", "1981-2000", "after 2001"). Reference buildings are articulated in 5 geographical zones.
Alongside the GCCA-based detailed study on space and water heating, also cooking, space cooling, electrical appliances, and lighting are accounted for.
All of the above analyses are combined to compute the overall residential sector consumptions in 2022, 2030 and 2050. The ODEX ("Energy efficiency index")[12] coefficient is then applied to adjust consumptions in accordance with the expected efficiency increase of the sector.

Key assumptions:

- 1% annual new construction rate.
- 1.8% annual renovation rate.
- For each household, a maximum of one technology substitution over the entire timespan of analysis.
- Oil dismission by 2030.
- No biomass use in urban environments, in accordance with existing environmental policy constraints[13].

9. Ratio between the global costs of the technological options and the related CO_{2eq} emissions avoided. The lower the indicator, the more convenient the technological option

10. ISTAT statistics, Available at: http://dati.istat.it/

11. FB: Focus Building

12. ENEA, Rapporto annuale efficienza energetica, 2017

13. Some Italian regions (i.e. Piemonte, Lombardia, Emilia Romagna) have imposed constraints to the installation of biomass heating systems in urban areas, due to local air pollution issues

ELECTRIFY ITALY / SUMMARY

- New buildings are assumed to be fully electric.
- Substitution of gas stoves with induction ones is concurrent with the electrification of space and water heating.
- Space cooling, electrical appliances, lighting: projections of historical consumptions trends.
- Incentive mechanisms fixed as in 2015 (Ecobonus and Conto Termico 2.0).
- Non-progressive concessional tariff for SFH with heat pumps as the sole space heating system.
- Energy price growth rates as per IEA projections[14].

With reference to scenario FB, another five scenarios have been developed to highlight some key barriers and drivers to the electrification of the residential sector, and to provide possible strategies to further foster electrification. With the exception of the assumption variation studied by each scenario, the other assumptions are the same as FB.

- ***Sensitivity analysis on renovation rate***
  Annual renovation rate[15] appears to be a key driver in the electrification of the building sector.
  Sensitivity 1: annual renovation rate equal to 1.2% (renovation rate for Italy).
  Sensitivity 2: annual renovation rate equal to 2.5% (maximum renovation rate for Europe).
- ***SCENARIO TRF***
  Extension of the non-progressive concessional tariff (already valid for SFH with heat pumps as the sole space heating system) also to heat pumps in MFH for space heating and to heat pumps in SFH and MFH for water heating.
- ***SCENARIO SP***
  Constant electricity and gas prices, fixed to 2015 values.
- ***SCENARIO TX_PM***
  Adoption of taxation on PM10 emissions[16] (0.87 €/gPM10, weighted for SFH and MFH proportionally to their relative consumptions) for space and water heating systems.
- ***SCENARIO TX_CO₂***
  Adoption of taxation on CO_{2eq} emissions (0.2 €/kgCO_{2eq}, weighted for SFH and MFH proportionally to their relative consumptions) for space and water heating systems.

Industry

The methodology used to assess the evolution of the industrial sector toward higher use of electrical appliances is based on the definition of a bottom-up simulation model based on the minimization of the levelized cost of heat - LCOH. For each time step (2022, 2030, 2050), for each industrial subsector, and for different temperature levels, the model computes the cost of heat production achieved by different technologies (electrical, gas, oil and coal) and updates the stock choosing least-cost solutions.

Key assumptions:

- Potential of electrification based on energy services (mechanical work, refrigeration, heating, lighting).
- The model investigates 9 electrical technologies and conventional gas, coal and oil technologies providing heat, at 5 different thermal levels.
- Key variables: capital cost, learning curves, conversion efficiency, technology improvement, inertial stock substitution, electricity/gas prices, carbon prices.
- Service and agriculture not included in the analysis.
- LCOH is calculated assuming a discount rate of 5%. An escalation in commodity prices, namely electricity-to-gas prices, is assumed based on data available from International Energy Agency[17].
- The model includes inertial stock substitution, estimated at 3% per year conventional technology stock substitution[18].
- The model neglects innovation in competitive gas technologies (e.g., biogas, biomethane, CCS, etc..). Only one indirect electrical technology, namely power-to-gas for hydrogen production, is considered.

The study considers the evaluation of electrification under two different scenarios according to the table below:

	DRIVERS			
	GDP and population	**Final energy consumption**	**Energy prices variation**	**CO_2 Prices**
High electrification	OECD projections	Trend Extrapolation[19]	ETP 2016	ETP 2016
Beyond high electrification	OECD projections	Trend Extrapolation	Cumulative advantage[20]	ETP 2016

The bottom-up simulation model estimates the stock accounting variation based on LCOH. For each time step, industrial subsector and temperature level, the model computes the cost of heat production achieved by

14. IEA, Energy Technology Perspectives (ETP) 2016, 2016

15. BPIE (Building Performance Institute Europe), Europe's buildings under the microscope, 2011

16. European Commission, Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements, 2012

17. IEA, Energy Technology Perspectives (ETP) 2016

18. Comitato Italiano Gas - CIG Forum 2018

19. IEA Statistics, https://www.iea.org/statistics/?country=ITALY&year=2016&category=Energy%20supply&indicator=TPESbySource&mode=table&dataTable=BALANCES

20. In this scenario, electricity experiences a progressive reduction of the competitive disadvantage of price. This is achieved by introducing a synthetic yearly growth rate of 0.9 in retail price for electricity, while setting the gas growth rate to 1.1 for the same period

different technologies and updates the stock accounting with least-cost solutions assuming an inertial stock substitution, estimated at 3% per year conventional technology stock substitution.
The model calculates the stock time variation of gas, electricity, coal and oil appliances for heat production and updates the total final energy consumption mix.

Transport

The transport sector analysis is based on the Fuelling Italy's Future study[21], complemented with an additional study of electricity penetration in urban and extra-urban public transport, and integrated with the projection of other transport modalities.
The analysis of road transport is based on modelling the consumption of different types of vehicles, taking into consideration the aerodynamic and internal friction efficiency, resistance proportional to mass, and inertial load. Based on the stock of vehicles and other constraints, the total consumption of different energy commodities is calculated.
Other transport systems (trains, aircraft and ships) are integrated on the basis of historical data provided by Eurostat, and projected considering an increase proportional to GDP growth rate. According to this model, the contribution of each transport mode to the consumption of each commodity is evaluated. The final values are added to consumption for road transport.
The resulting transport model integrates city and long-range buses, air and maritime transport, trains, light commercial vehicles and passenger cars.

Key assumptions:

- Cost of batteries and electric powertrain decreases by 60% and 25% respectively from 2015 to 2050.
- The efficiency of energy conversion and powertrain of electric vehicles increases 3 points from 2015 to 2050.
- City buses are 100% electric by 2050, assuming that Milan will have a fully electric fleet by 2030, while other cities are assumed to be slower in the substitution of ICE buses.
- Market and stock share of passenger cars is assumed by the Fuelling Italy's Future study–TECH Scenario.
- A slower uptake of EV (including PHEV) in LCV sector will bring EV penetration at passenger cars level in 2030.
- The electrification of long-distance heavy vehicles (coaches and trucks) reaches a penetration of 20% and 25% in 2050, starting to be relevant in 2030.

ITELEC2050 SCENARIO COMPOSITION

The outputs of sectoral studies are merged as inputs of a single scenario called ITELEC2050.

21. Fuelling Italy's Future study, https://www.enelfoundation.org/content/dam/enel-found/news-pdf/news-pdf-2018/Fuelling_Italys_Future.pdf

In order to build the ITELEC2050 scenario, the following sub-scenarios at supply and demand sides have been selected:

- ***RES:*** Current Policy scenario selected. It represents an intermediate among the ones elaborated with different assumptions on CO_2 prices. This choice is based on the consideration that the impact of higher CO_2 prices is relatively limited in terms of CO_2 emissions and electricity production mix.
- ***Residential buildings:*** FB scenario selected. This scenario better reflects the current market regulation and business model in terms of incentives, tariffs and energy prices in comparison with the alternative scenarios, which have been developed to assess the impacts of some key variables on the electrification of the sector. In particular, the incorporation of a CO_2 price approximates the implementation of policies for decarbonization and energy efficiency. The use of the GCCA indicator is consistent with this choice, thus representing compliance with current policy targets, which are mainly focused on GHG emission reduction.
- ***Industry:*** High electrification scenario selected. This reflects major international trends in commodity cost variation, learning curves, efficiency gains, and carbon pricing.
- ***Transport:*** The TECH scenario has been built based on the FIF study related to passenger cars by adding on analyses of public transportation (urban and long-range buses), air and water transport, trains, and light commercial vehicles.

KPIs

A set of KPIs has been defined and calculated for ITELEC2050. The KPIs aim to assess the benefits of electrification in four dimensions: energy, economy, environment, and society.
Energy KPIs aim to understand the overall impact of electrification on the energy system. KPIs include electrification rate, total primary energy supply, total final consumption, and contribution of electrification to the overall reduction of consumption.
Environmental KPIs aim to highlight the benefits of electrification for the environment at both global (CO_2) and local (pollutants) levels. KPIs include CO_2 and pollutant emission reductions, and the contribution of electrification to these.
Economic KPIs serve to evaluate the impact of electrification on national economics. Indicators include energy intensity and carbon intensity, giving an indication of how electrification can contribute to the creation of an economic system in which economic growth can coexist with decreasing energy consumption and emissions.
Social KPIs aim to deepen the direct benefit that electrification can have on peoples lives, both on economic and quality of life levels. Indicators include the reduction of family income share required for energy needs and the healthcare savings connected to air pollution reduction (mainly PM10 and NO_x).

4. MAIN RESULTS

The ITELEC2050 scenario shows that the electricity triangle can represent a viable, effective solution to address the issues of the current energy paradigm.

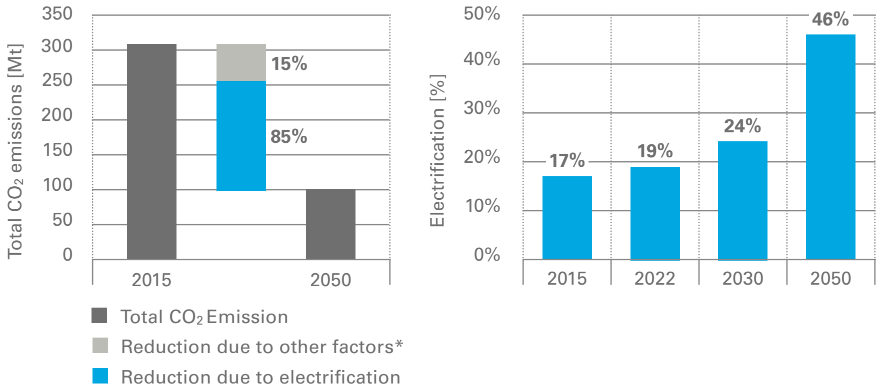
- ***Environment:*** -68% CO_2 emissions in 2050, with an electrification contribution of 85%.
- ***Health:*** €692 billion cumulated savings thanks to reduced healthcare expenditures, productivity recovery, and human lives saved.
- ***Affordability***:-17% in energy expenditures for Italian families[22].

This is achieved:

- On the supply side, thanks to the high penetration of RES (85.6% in 2050), with solar playing a key role.
- On the demand side through the penetration of electricity for final uses, up to 46% in 2050.
- From a sectoral point of view, residential building and transport sectors have the largest electrification growth potentials from 2015 to 2050 (from 15% to 53% and from 3% to 41%, respectively), while the industrial sector, already highly electrified, can further improve (from 39% to 42%).

ENVIRONMENT

The energy transition can substantially contribute to decarbonization, with a progressive reduction of studied sector emissions up to 68% in 2050 compared to 2015.
Electrification will reach 46% in 2050, thus contributing to 85% of carbon emission reduction. The rest of the reduction is attributable to an overall increase of efficiency in the use of other energy sources.



* Increase of average efficiencies of non-electric technologies

Figure 5
Contribution of electrification to carbon emission reduction and future electrification of demand sectors.

22. Including the effect of average income increase

These results underline the ***importance of electrification*** in the context of the objectives of carbon emission reduction to ***tackle climate change.***

HEALTH

The energy transition can have a key role in reducing pollutants, with an emission reduction of 76% of PM10 and 69% of NO_x by 2050. The benefit on public health translates in a cumulated saving of €796 billion in 2050 due to the reduction of healthcare expenditures, recovery of lost productivity, and avoidance of premature deaths. Electrification will contribute up to 87% of this reduction, equal to €692 billion in 2050. The rest is due to commodity shift and increased efficiency of traditional tecnologies. Buildings will contribute the most to this benefit, followed by transport and industry, mainly due to the decrease of biomass (the highest PM10 and NO_x emitter) in the residential sector in 2050.

AFFORDABILITY

Electrification will boost energy affordability for Italian families. Ruling out the effect of an increase in average income, the share of income that a family will need to devote to energy expenditures will decrease by10% by 2050 (17% inlcuding the effects of average income increase). Even if the average income does not increase and wealth distribution does not improve in the years to come, electrification will improve the impact that energy expenditures have on a family budget. This will presumably also induce positive feedback supporting further penetration of electrical technologies. This effect is not taken into account in this study.

SUPPLY SIDE: RENEWABLES

Renewables will be a key factor in a sustainable energy system. Their penetration in power generation will steadily increase up to 85.6% in 2050 (45% in 2022, 59% in 2030), almost 120% more than the current level.
A strong penetration of renewables is possible even without considering the effect of environmental externalities. In fact, even considering a zero CO_2 price, renewable sources are projected to reach 84% by 2050 (48% in 2022, 56% in 2030).
Moreover, even a very high CO_2 price (e.g. up to 191 €/ton in 2050) would not result in dramatically higher RES penetration rates (90% in 2050).
Solar PV will play a key role, with a penetration of 62% by 2050 (24% in 2022, 34% in 2030). The growth of wind and hydro is indeed constrained by intrinsic resource limitations, while for solar power, the only theoretical limitation is the surface available for panel installation.
The level of penetration projected is reachable with an extension of about 1,400 km^2, just 1.1 times the area of Rome municipality. This measure is a conservative maximum upper value as it does not consider any improvement in the efficiency (kW/m^2) of solar PV technology.
Energy storage can address the variability and uncertainty in RES. Italy's power system can already rely on pumped hydro storage, which is assumed

to stay at a constant level, although this study shows that additional battery capacity will be needed in the future.
According to this study's projections, storage will indeed play an increasingly important role over time, with a projected installed capacity of about 112 GW, out of which 106 GW will be represented by electrochemical batteries.
Interestingly, the economic optimum does not include battery storage until 2030 when some investment in battery storage occurs under the high emissions price scenario. However, in 2050 when the cost of battery storage is assumed to be substantially lower, the model finds it economically beneficial to install large amounts of battery storage, particularly in scenarios with non-zero CO_2 prices.

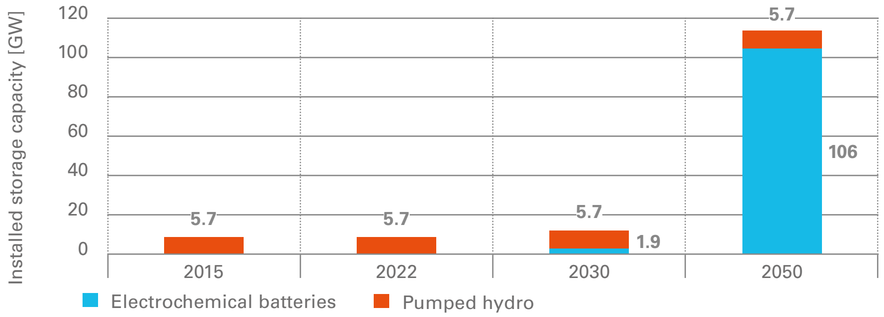


Figure 6
Installed energy storage capacity.

The growing role of renewables in the energy mix could be enhanced and consolidated by the adoption of long-duration energy storage. In a scenario with a growing share of renewables, it is necessary to guarantee system stability and overcome the barrier represented by the inherent exposure to the cannibalization effect: low short-term prices when resources are available, and low generation when prices are high, which substantially affects the revenue streams of these sources. Long-duration energy storage, on which promising research and development projects are ongoing[23,24,25], may represent one of the key innovative technology tools able to predictably control the output of renewable sources and to stabilize their market revenues, thus increasing their stability and economic viability while helping to provide enough flexibility in systems with close to 100% renewables.
Finally, it is worth noting how tools such as PPAs (Power Purchase Agreements) can be used to mitigate the above-mentioned risk and are expanding worldwide. This is due to an increasing number of commercial companies willing to improve their sustainability profile by using renewable energy, as well as advertising their products and services as "made with renewable energy". Such an increasing consumer demand for "green products and services" will further sustain the penetration of renewable energy sources.

23. "Lowering the Bar on Battery Cost" Yet-Ming Chiang, Liang Su, Mengshuan Sam Pan, and Zheng Li; Joule 1, 212–219, October 11, 2017

24. "Air-Breathing Aqueous Sulfur Flow Battery for Ultralow-Cost Long-Duration Electrical Storage", Zheng Li, Menghsuan Sam Pan, Liang Su, Ping-Chun Tsai, Andres F. Badel, Joseph M. Valle, Stephanie L. Eiler, Kai Xiang, Fikile R. Brushett, and Yet-Ming Chiang; Joule 1, 306–327, October 11, 2017

25. "Long Duration Energy Storage, and the Future of Renewables Generation", Enel Foundation and Form Energy Inc. research ongoing at the time of writing

DEMAND SIDE

From a demand point of view, electrification (i.e. the electricity share in total final consumption), can increase up to 19% in 2022, 24% in 2030 and 46% in 2050.
Out of the 46% electrification rate in 2050, 20% is linked to the residential building sector, 13% to industry and 13% to transport.
The evolution of the energy system in this way will lead to a strong reduction in total final consumption (-42% in 2050). Electrification will contribute to more than 3/4 of this reduction, thanks to the higher efficiency of electric technologies compared to their traditional equivalent. The highest contribution to the reduction of TFC is the electrification of the transport sector, contributing 42% of TFC reduction, followed by buildings (31%) and industry (8%).

Demand side sectoral view: overview

Industry will conserve a high electrification rate, which will further grow from 39% to 42%.
The sector that has the largest growth potential is transport, which may grow by twelve times the current rate.
Also, the residential sector has a substantial threefold growth potential. Overall, the building sector has the potential to become the most electrified sector (53% in 2050) followed by industry and transport.

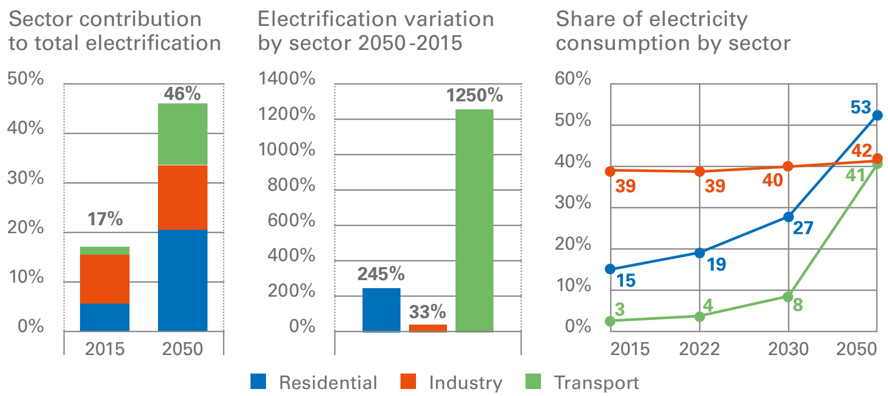
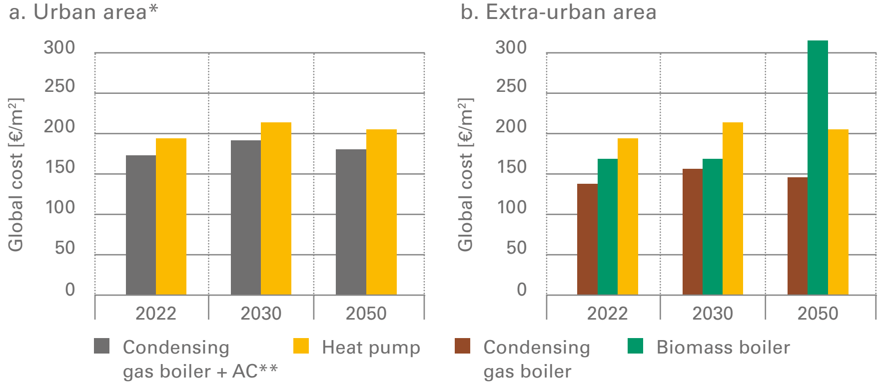


Figure 7
Electrification sectoral view.

Demand side sectoral view: residential buildings

Customer choices are a key factor in the process of electrification of the residential sector and are driven by a variety of factors. Economic convenience is one of the most important, and therefore traditional technologies are still favoured in some cases. Indeed, from a purely financial viewpoint, electrical technologies are already competitive in the market, but with a slight disadvantage. This is mainly due to higher investment costs for electrical technologies with respect to traditional ones, as well as higher energy prices for electricity. Under current conditions in urban areas, the extra global costs[26] of electrical technologies are always lower than 15% (Figure 8a), while extra-costs compared to biomass technologies are more variable depending on the context. In particular, in an extra-urban context (Figure 8b), biomass technologies will still be slightly more economically convenient in 2022 and 2030 (extra costs range between +10% and +25%), while energy commodity price projections[27] favour heat pumps in 2050. It is important to note that, in urban areas, the cost for a multi-split air conditioning system is computed as part of the global cost for gas technologies, representing an opportunity cost that permits a comparison of the services that these solutions can provide (heat pumps can provide both heating and cooling services at once).



* Some Italian regions (i.e. Piemonte, Lombardia, Emilia Romagna have imposed constraints to the installation of biomass technologies in urban areas, due to local air pollution issues.

** In urban area, the cost for a multi-split air conditioning system is added to the global cost for gas techs, representing an opportunity cost that permits to compare the services that the solutions can provide (heat pump can provide both heating and cooling services).

Figure 8
Annual global cost (€/m²) for different technological solutions, in urban (a) and extra-urban (b) areas. Case study: multi-family house, built before 1980, NW Italy, space heating, 20 years lifetime.

Electric technologies are the most environmentally sound, and represent, among the analyzed technological solutions, the best compromise between PM and CO_2 emissions. Conversely, gas technologies are the worst in terms of CO_{2eq} emissions, while biomass is the highest PM emitter.

For this reason, environmentally-friendly consumer choices can be incentivized by appropriate policy measures, which can impact costs, and thus help the electrification process. An analysis of the delta global cost between electrical and gas technologies for the urban area (in which biomass is excluded), and between electrical and biomass technologies in the extra-urban area (in which biomass can still be convenient), allows to evaluate the extent to which other technologies are still more economically convenient than electric ones. Moreover, different scenarios were built to be compared with the reference scenario (scenario FB), based on the current situation.

In an urban context (Figure 9a) in which gas and electrical technologies compete, a PM taxation (scenario TX_PM) has a marginal effect, whereas taxation on CO_2 (scenario TX_CO_2) can help to reduce the extra-cost of electrical technologies. However, in these situations, environmental costs are not enough to ensure the economic convenience of heat pumps in all contexts. Appropriate financial measures such as the extension of the non-progressive electric tariff for heat pumps (scenario TRF) and fixed prices growth rates for gas and electricity (scenario SP), can reverse results, clearly advantaging heat pumps over competing technologies.

In the extra-urban context (Figure 9b), consumer choices could move significantly toward electric technologies if the environmental cost is reflected in the final cost for the customer. Here, the additional financial burden borne by a consumer choosing an electric technology can be reduced by more than 20% if a tax on PM10 (scenario TX_PM) is associated with the environmental impacts of the solution. In this context, financial measures have a lower impact on the competition.

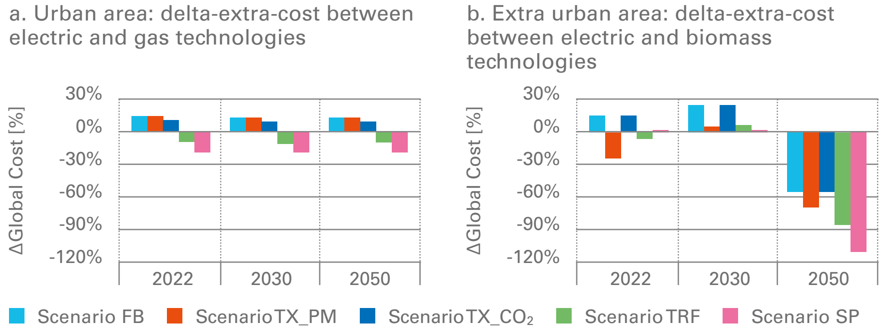


Figure 9
Delta global costs of heat pumps with respect to global costs of the competing technological option for MFH < 1980 North-West – space heating. a) left: gas-heat pump competition (urban area); b) right: biomass-heat pumps competition (extra-urban area).

Therefore, policies are needed to lower the barriers hindering massive adoption of technological options with the greatest environmental performance. In this framework, this study section assesses the effects of relative convenience incorporating the valorization of key environmental aspects (e.g. carbon and pollutant emissions) and investigates the potential for electric penetration in the residential sector based on optimal environmental choices.

To do so, a new indicator named ***Global Cost for CO_{2eq} Avoided (GCCA)*** is defined. This indicator is able to couple the global cost (considered as the main driver from a private point of view) and the potential for CO_{2eq} reduction (a key driver from the public perspective). GCCA is calculated as the ratio

26. Global cost is defined as the total cost of a system over its lifetime. The calculation accounts for the initial investment cost of the intervention and the annual costs (discounted at the present value with a constant rate), including maintenance and energy costs. In this study, incentives are added to the formula

27. Energy costs for the base year are defined according to ARERA and Unione Petrolifera. Projections for all the energy commodities are derived from IEA growth rates for 2022, 2030 and 2050 (ETP 2016)

ELECTRIFY ITALY / SUMMARY

between the global costs of technological options and the correspondent CO_{2eq} emissions avoided, and it allows the identification of the optimal technologies for carbon emission reduction. The lower the indicator, the more competitive the technology is when a retrofit occurs.

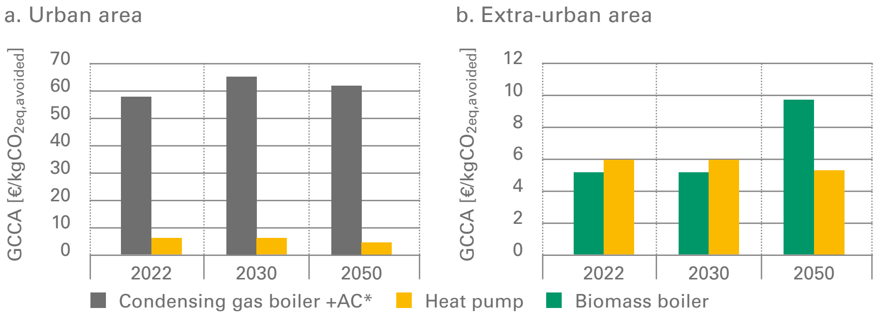


Figure 10
GCCA indicators in 2022, 2030 and 2050 for MFH < 1980 North-West – space heating. a) left: in urban area; b) right: in extra-urban area.

* In urban area, the cost for a multi-split air conditioning system (AC) is added to the global cost for gas techs, representing an opportunity cost that permits to compare the services that the solutions can provide in equal terms (heat pump can provide both heating and cooling services at once).

Based on the indicator, in urban areas, electrical technologies are preferred to gas ones. In extra-urban areas, there still is competition between biomass and electricity up until 2050, when electrical technologies are preferred.
Accordingly, scenario FB is built based on the minimization of the GCCA indicator for the overall residential stock, highlighting that the building sector has a high electrification potential that can be captured with currently existing technologies. According to this scenario, the penetration of heat pumps for space and water heating can grow 27 and 7 times respectively by 2050 compared to 2015, reaching about 21 million units each.

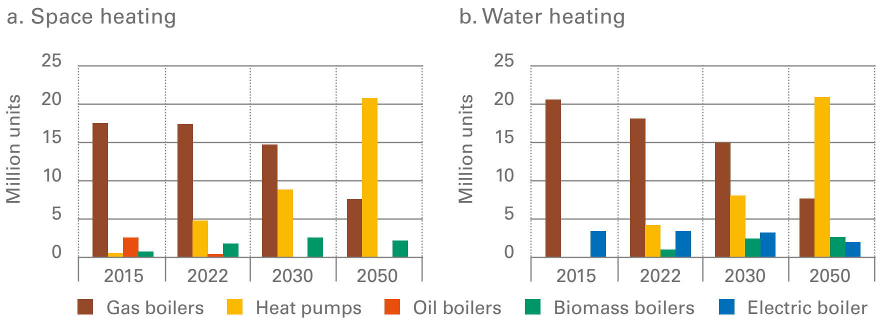


Figure 11
Technological mix in 2015, 2022, 2030 and 2050 for thermal uses (space heating and water heating) in residential buildings (both urban and extra-urban) in terms of number of units. a) left: space heating; b) right: water heating.

Considering the overall residential sector (i.e. including all other uses: space cooling, cooking, lighting, and appliances), the study found a forecasted electrification potential of 53% for the entire Italian residential sector (19% in 2022 and 27% in 2030), including both urban and extra-urban buildings. This means that the energy consumption of electricity up to 2050 is expected to represent more than half of total consumption for the whole sector, against the current 15% (with respect to the baseline of the study, namely 2015).

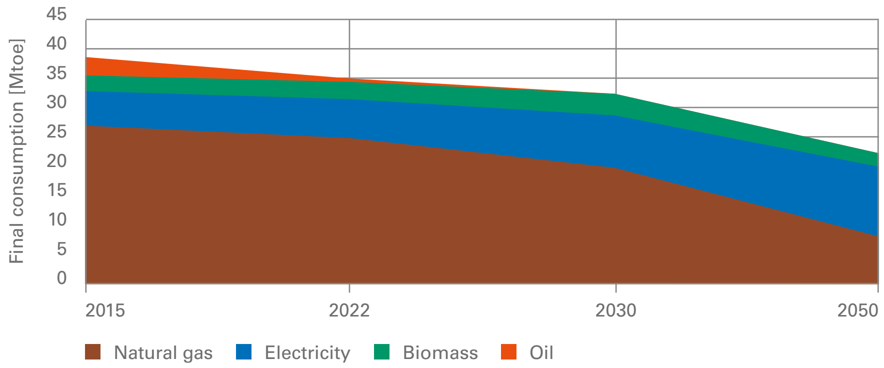


Figure 12
Final energy consumption [Mtoe] by fuels in 2015, 2022, 2030 and 2050 for the overall residential sector.

Penetration of new technologies is marginally affected by measures such as concessional electric tariffs and fixed prices for gas and electricity, whilst measures encouraging renovation rates have the potential to accelerate technology substitution (when varying the renovation rate from 1.2% to 2.5%, the electrification potential ranges from 43% to 66% in 2050). This confirms that, besides the upfront investment cost, one of the key barriers is the inertia of current traditional technologies. Moreover, to unlock the electrification potential that could be captured with existing technologies, a surge in renovation rates would be a key driver.
As for the direct impact of climate change, when considering buildings, it is necessary to take into account the impact of increasing summer temperatures on public health, as an increase in the number of hot days due to climate change will increase the mortality risk[28]. As an example, in 2003, an unexpected heatwave in France caused 15,000 deaths, 80% of which were over 75 years old. Subsequently, the French government requested that all retirement homes have at least one room air-conditioned to less than 25°C on each floor during extreme periods of heat.
If we consider that in Italy the percentage of people over 75 will steadily grow, reaching 21% in 2050, and that the number of hot days[28] will increase, it is clear that the situation in France in 2003 is unfortunately destined not to remain isolated, if adequate mitigating strategies are not undertaken.
Therefore, it is reasonable to expect that, to tackle this issue and to address the need to maintain an adequate comfort level in buildings, the demand for air conditioning will grow. The energy demand for air conditioning for both residential and non-residential buildings due to the simultaneous effect of a rise

28. The Imperative for Climate Action to Protect Health, Andy Haines, M.D., and Kristie Ebi, M.P.H., Ph.D., The new England Journal of Medicine, January 17, 2019

ELECTRIFY ITALY / SUMMARY

in AC installations and increase of hot days[29] is expected to increase by 81% from 2015 to 2050, with an additional electricity demand of +21 TWh. The effect of hot days alone will increase the energy demand for air conditioning by 12.3%, equivalent to more than 5 TWh.

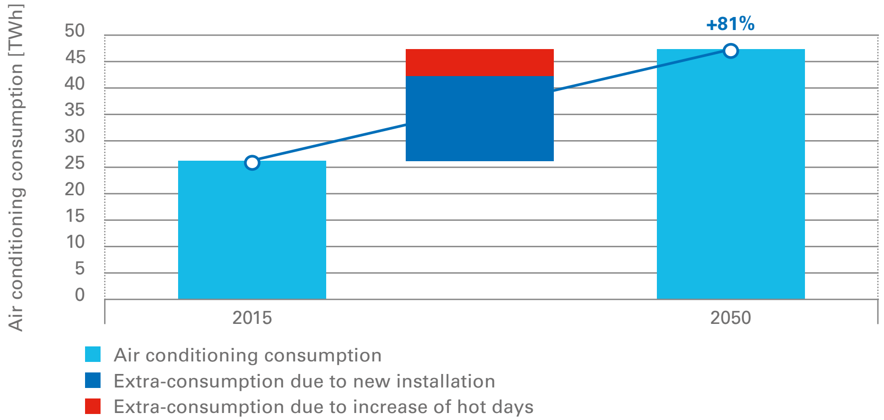


Figure 13
Air conditioning consumption in residential and tertiary sectors.

Demand side sectoral view: industry

The industrial sector is already highly electrified with a share of about 39% in 2016, with total electricity consumption at about 209 TWh.

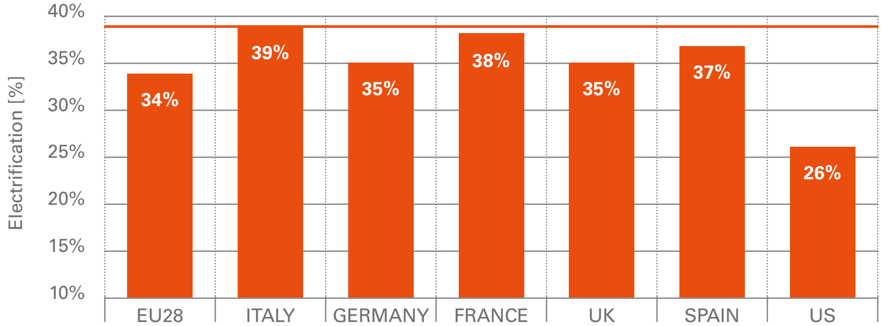


Figure 14
Industry electrification: an international comparison.

According to the "High electrification" scenario, the industrial sector can capture further electrification potential, reaching an electrification rate of about 42% by 2050 (approximately +3% compared to 2015) by progressively introducing low and low-to-medium temperature heat pumps. This corresponds to an additional 3.1 TWh annual electricity demand, equivalent to 76% of the low and low-to-medium temperature heat demand in 2050.

29 According to ISTAT definition, hot days are those with external air temperature greater than 25°C

From a purely technological perspective, that considers only availability and technology maturity, electrical appliances could potentially be introduced in all sectors at different temperature levels, with a theoretical potential of 88 TWh thermal energy by 2030 (Figure 15).
Nevertheless, by introducing economic constraints, it is possible to estimate what fraction of this theoretical potential can be captured, as shown in Figure 16 for low-temperature heating appliances.

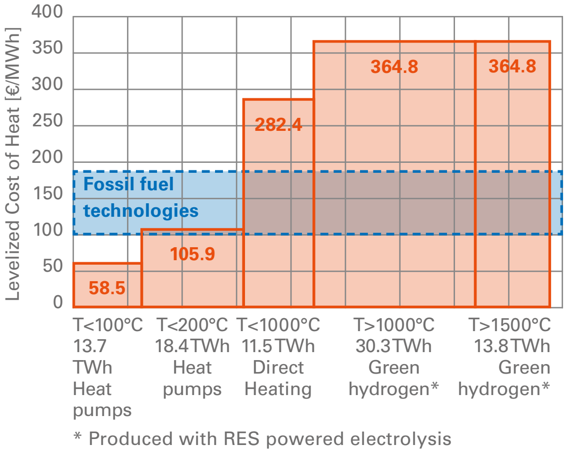


Figure 15
LCOH merit order, by potential and temperature range for the year 2030. Green hydrogen refers to power-to-gas technologies fed on renewable power sources.

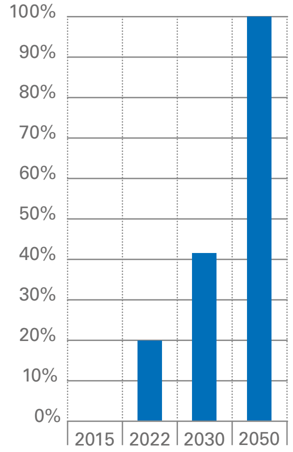


Figure 16
Share of low-temperature heat provided by electrical appliances.

Low temperature (<100°C)

Due to high conversion efficiency (COP range 3.5 - 5.5 for low-temperature heat pumps vs. 0.75-0.9 efficiency of a gas boiler), low-temperature heat pumps are already in competition with gas appliances. Their 13.7 TWh thermal energy potential in 2030 can be captured at 43% due to the inertial stock substitution.

Low-to-medium temperature (100°C - 200°C)

Due to high conversion efficiency (COP range 2 - 3 for low-to-medium temperature heat pumps vs. 0.7-0.8 efficiency of a gas boiler), low-to-medium temperature heat pumps will become competitive technologies with gas appliances after 2030, when the electricity-to-gas price ratio is below 3.5. They capture 40% of heat production potential in 2050.

Medium temperature (200°C - 1000°C)

It appears that electrical appliances for medium temperature applications are not competitive as the efficiency advantage compared to gas technologies is not enough to counterbalance the comparatively high cost of electricity. In 2050 the breakeven would be at a ratio of 1.5 (57% lower than IEA estimates), compared to the present 3.9. The value of providing flexibility services to the power grid and low-cost on-site generation from renewables could improve the competitiveness of these electrical appliances.

High-temperature (1000°C - 1500°C)

High-temperature solutions (e.g. hydrogen production), characterized by efficiencies slightly lower than their traditional equivalent, are not competitive due to the high capital cost and comparatively high cost of electricity. To be competitive with gas, industrial hydrogen use for high and ultra-high temperature applications would require electricity-to-gas price ratios of 0.7 at 2030 and 1.1 at 2050 (meaning 80% and 70% lower than IEA estimates).
Sector coupling, on-site renewable power sources and/or market designs that reward flexibility and storage could provide those conditions. Sector coupling, i.e. the integration of power and gas infrastructure, could promote high-temperature solutions. Power-to-gas technologies may produce low-cost "green" hydrogen (i.e. produced with electrolyzers using mostly renewable energy), as well as provide ancillary services by avoiding power grid congestions and mitigating temporal and geographical mismatches between electricity generation and consumption.

Ultra-high temperature (>1500°C)

Ultra-high temperature electrical technologies (e.g., electric arc furnaces, not represented in Figure 15) are mature and competitive with conventional gas or coal blast furnaces. However, their introduction in the technology mix requires a major change in basic metal processing; therefore, coal-based blast furnaces are assumed to provide ultra-high temperature heat.

Based on the above considerations, the findings of this study suggest that it is possible to increase electrification in the industrial sector, especially providing high efficiency low and low-to-medium temperature heat as indicated in Figure 16.
In particular, low-temperature heat pumps can add 1.3% of electrification in 2030, equivalent to 1.4 TWh of additional yearly electricity demand, corresponding to 43% of the low temperature heat demand. Low and low-to-medium temperature heat pumps can add 3.4% of electrification in 2050, equivalent to 3.1TWh additional electricity demand annually, and corresponding to 76% of the low and low-to-medium temperature heat demand.

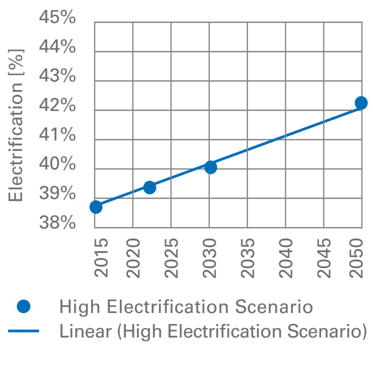


Figure 17
Electrification potential in Italian Industry.

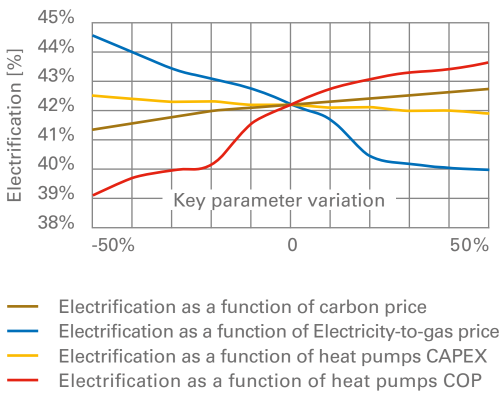


Figure 18
Sensitivity analysis: electrification of industry in 2050 as a function of key parameters variation vs. High Electrification Scenario assumptions.

In Figure 18, sensitivities show how variations of key assumptions can affect electrical technology penetration.
Electricity-to-gas price ratios, conversion efficiencies, carbon price, and CAPEX are the main parameters affecting electrification in the industrial sector, with electricity-to-gas price ratios, carbon pricing and conversion efficiencies giving the highest sensitivity.
Reducing the electricity-to-gas price ratio by 50% with respect to International Energy Agency estimates for 2050 could add up to 3% more electrification. Almost 2% of higher electrification can be achieved with 50% higher COPs of low and low-to-medium temperature heat pumps.
On the contrary, the sensitivities confirm that the penetration of medium- and high-temperature electrical appliances is unlikely to happen according to the current outlook. In 2050, the electricity-to-gas breakeven price ratio that enables the penetration of induction ovens is about 1.4, or 60% below IEA baseline estimates. Industrial hydrogen utilization can be profitable with electricity-to-gas price ratios lower than 1.1, 70% below IEA baseline estimates.
The effect of key parameters on the share of electrification in the industrial sector has been further analysed, and results are shown in Figure 19 and Figure 20.
Figure 19 shows the share of electrification in the industrial sector as a function of electricity-to-gas price ratios. Sensitivity to electricity-to-gas price ratios is considered with -50% to +50% variation with respect to the baseline value of 3.4 at 2050. Electricity-to-gas price ratio variations have the potential to change from -2% to +3% electrification at 2050. Variations affect the year in which low and low-to-medium temperature electrical heating appliances become less/more profitable with respect to gas technologies, thus promoting a delayed/early adoption by industrial users.
Figure 20 shows the share of electrification in the industrial sector as a function of carbon prices. Sensitivity to CO_2 prices are calculated with -50% to +50% variation with respect to the High Electrification Scenario assumption of 140.9 €/t_{CO2} by 2050. Carbon prices have the potential to vary the electrification rate by -1% to +1% in 2050 due to the change in the cost of heat production from fossil-fed heating appliances.

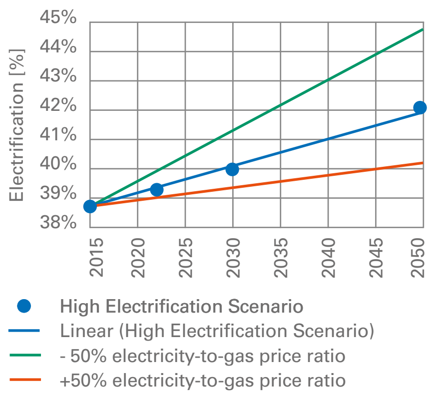


Figure 19
Sensitivity analysis: electrification of industry as a function of electricity-to-gas price ratios vs. High Electrification Scenario assumption.

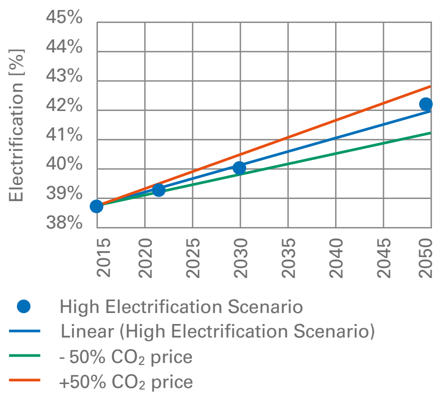


Figure 20
Sensitivity analysis: electrification of industry as a function of carbon prices vs. High Electrification Scenario assumption.

ELECTRIFY ITALY / SUMMARY

A high share of RES in the power sector would create an emission factor of electricity generation lower than 51 kg_{CO2}/MWh_e, thus including a low contribution from environmental externalities to electricity prices. Therefore, high carbon prices would sustain the introduction of electrical appliances in sectors with high emissions such as industry.
Besides the price of CO_2, gas and electricity, other factors can enhance the penetration of electrical technologies. Efficiency and emission targets, demand response, on-site generation, low electricity cost for power-to-gas applications, and sector coupling could promote these technologies and spread hydrogen use in industry. In particular, demand response to participate in flexibility markets could change the economics of electrical appliances not yet convenient at current electricity-to-gas price ratios and conversion efficiencies. Thus, flexibility requirements in the power sector could support the penetration of low-to-medium and medium temperature electrical appliances. On the other hand, sector coupling of power and gas sectors through power-to-gas technologies could support the indirect electrification of the industrial sector, producing low-cost hydrogen as an energy carrier for high and ultra-high temperature applications. Some of these factors depend on the specific regulation and market design adopted, thus confirming the key role of regulation in the electrification process.
Energy efficiency targets that promote the adoption of technologies enabling the reduction of primary energy consumption per unit of physical output can enhance the penetration of electrical technologies, typically characterized by higher efficiencies. Environmental regulations[30] aimed at reducing both CO_2 and pollutant emissions may also change the pace of industrial electrification, bolstering the adoption of electrical appliances that will avoid environmental costs.

Electrification may be an enabler for the entry of industrial stakeholders into the energy market who can combine both capacity and flexibility opportunities from new electricity market designs that appropriately value these services.
Demand Response (DR) is an alternative and less costly way to balance the grid by adjusting the load according to generation capacity. It has multiple sources of value:

- By avoiding investments in peak generation - capacity value.
- By providing reserves for TSOs - flexibility value.
- By balancing supply and demand locally and avoiding congestions - network value.

Commercial and industrial consumers can respond to market variations by increasing or reducing their energy consumption with the aim of responding to peaks in electricity supply and demand, resulting in greater grid flexibility and stability as well as more efficient use of energy infrastructures and resources.
If electrified, certain industrial processes can be stopped on demand, in response to a price signal or a communication (remotely controlled devices, etc.) that usually correspond to specific grid emergencies (e.g. extreme events, price spikes, unexpected system issues).
Aggregation may provide further potential for flexibility and capacity, enabling the participation of industries to new electricity markets as virtual aggregated units. Thanks to digitalization, DR aggregators are able to create values both for the customers and for the utilities/TSOs: their role is to connect energy users to market opportunities in order to balance supply and demand.
Practical examples of energy reduction strategies to implement DR include:

- For cement manufacturing: stop primary and secondary crushers or stop proportioning and grinding mill.
- For industrial gas production: shut down air separation units and associated pumps.

Participation in capacity markets may be further enhanced by adopting dispatchable on-site generation solutions such as CHP systems or RES + Storage configurations. Moreover, low LCOEs of local generation solutions may increase the profitability of electrification of industrial final uses.

Demand side sectoral view: transport

The passenger car sector has a large electrification potential, with further benefits from public transportation and long range buses.
The share of electric vehicles is going to increase strongly in the coming decades due to two main factors: the reduction in the total cost of ownership and the likely increase in environmental restrictions in urban areas. According to the FIF[31] study, the number of electric passenger cars may increase up to 83% of the total fleet in 2050.

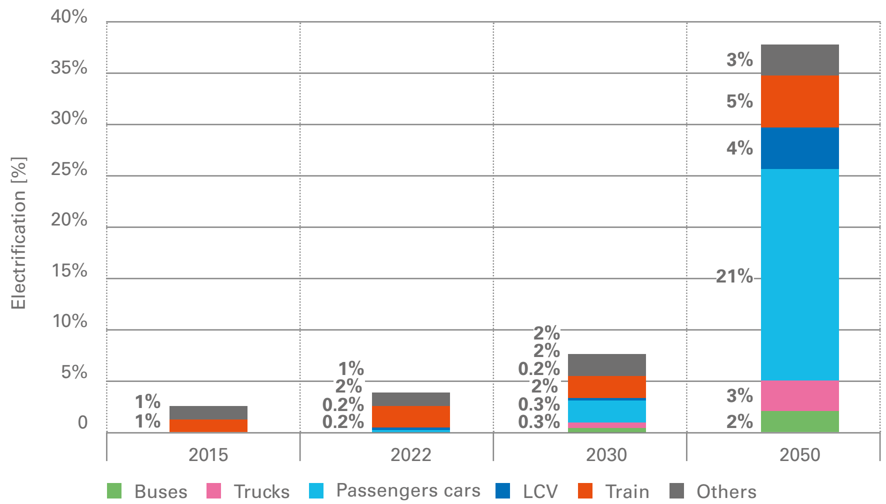


Figure 21
Penetration of electrification in transport sector.

30 As an example, the Italian National Energy Strategy claims for a reduction of greenhouse gas emissions to be two third of the value of 2005 in 2030, being even more ambitious for the sectors that are under the Emission Trading Scheme foreseeing a reduction of 57% on the same baseline. Concerning air pollutants, the new European Directive 2016/2284 imposes new limits on most relevant emissions including the SO_2 reduction of 71% by 2030, NO_x reduction of 65% by 2030, COVNM reduction of 46% by 2030, NH_3 reduction of 16% by 2030, PM2.5 reduction of 40% by 2030

31 Low-carbon cars in Italy: A socioeconomic assessment, Cambridge Econometrics, 2018" (link: https://www.camecon.com/wp-content/uploads/2018/09/FIF-Technical-Report.pdf).

ELECTRIFY ITALY / SUMMARY

Electrification leads to a strong increase in the efficiency of passenger cars. Although the total amount of km remains roughly constant, total energy consumption decreases by 92% in 2050 with respect to 2015.

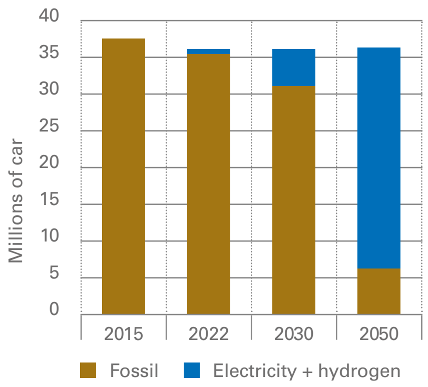


Figure 22
Evolution of electrification in passenger cars.

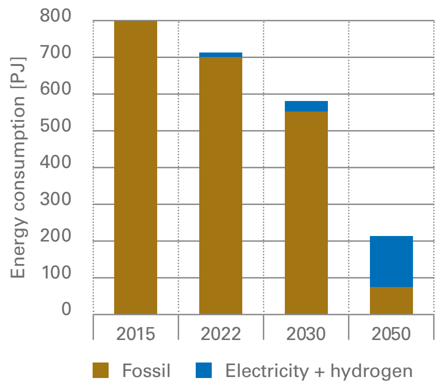


Figure 23
Energy consumption of passenger cars.

Additional electrification opportunities will come from public transport. EU regulations are encouraging the penetration of electric buses.

- The directive 2009/33/EC (Clean Vehicles Directive) on the promotion of clean and energy-efficient road transport vehicles sets the regulatory requirement of energy efficiency, CO_2 and pollutant emissions as an evaluation criterion in all the tenders related to the procurement of road vehicles. The directive is currently under revision. When in force, the updated directive will set minimum targets for the public procurement of clean vehicles, differentiated by Member State and by vehicle category. For Italy, the objectives for the procurement of a fleet of clean buses are 45% from 24 months following the date at which the Directive comes into force, to 31st December 2025, and 65% from 1st January 2026 to 31st December 2030.
- Initiatives like the European Clean Buses Initiative[31] aim to promote the penetration of clean buses by setting a 30% target penetration of alternatively fueled buses by 2025.

Public transport operators are responding by increasing the share of electric vehicles in their fleet.
ATM (Milan's municipal public transport agency) has already committed to transforming its fleet by 2030, with 1,200 extra electric buses. Dutch provinces will purchase only zero-emission vehicles starting in 2025. Several cities and regions have announced plans to stop purchasing conventionally fueled buses, including Copenhagen (in place since 2014), London (2018), Berlin (announced for 2020) and Oslo (announced for 2020)[32].

32. *https://ec.europa.eu/transport/themes/urban/cleanbus_en*

In Italy, considering the leading effect of Milan, it is reasonable to believe that the national fleet of local public transport buses could be 100% electric by 2050.

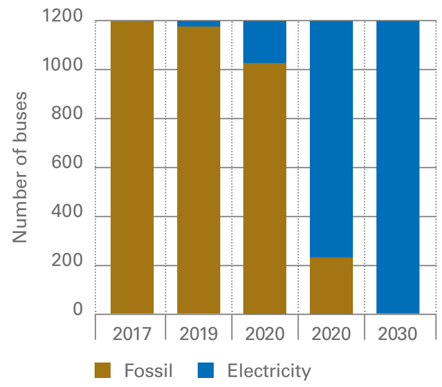


Figure 24
Penetration of electric urban buses, plan of Comune di Milano.

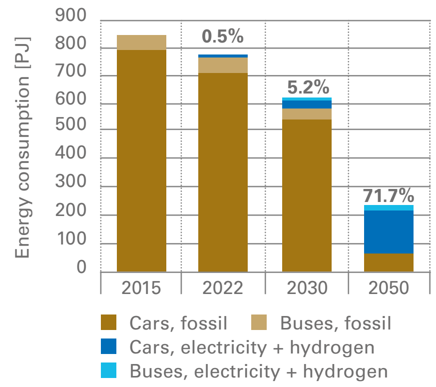


Figure 25
Total consumption of public transport systems.

Moreover, long-range coaches have the potential to further expand this market. Electric buses with a range up to 400 km are already available on the market. In 2017 a prototype built by Proterra set a world record of 1,102 miles (1,763 km) on a single charge.
It is therefore not unreasonable to expect an additional electricity penetration in the long-range bus division. The reduction in the cost of batteries, which is expected to drop from 237 €/kWh in 2016 to 70 €/kWh in 2050[33] enables a penetration rate of 20% for electric coaches in 2050. This would bring the reduction of consumption for long-range coaches up to 22 PJ, 21% of the 2015 value.

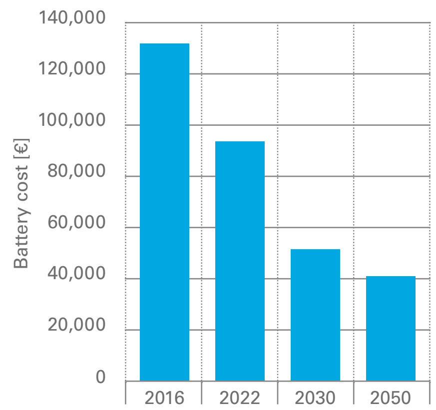


Figure 26
Cost of a 500 km battery for a heavy vehicle.

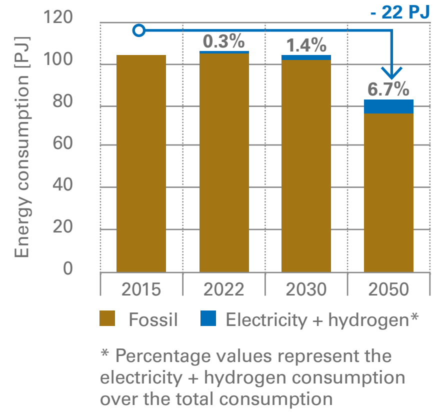


Figure 27
Total consumption of long-range transport systems.

33 Low-carbon cars in Italy: A socioeconomic assessment, Cambridge Econometrics, 2018" (link: https://www.camecon.com/wp-content/uploads/2018/09/FIF-Technical-Report.pdf).

FINAL REMARKS

Carlo Tamburi
Head of Italy
Enel

It is now a shared vision that economic development cannot ignore the principles of environmental and social sustainability.

There is an increasingly urgent need to fight climate change through the decarbonization of our economy. This is a clear objective towards which policy makers and the business world are directing their efforts.

Global, European and National Institutions and industrial players are at the forefront of the transformation of the energy sector from fossil-based to a zero-carbon approach.

These issues have now strategic value in the political agendas of many countries that have signed up to ambitious objectives for the fight against climate change to be pursued through the development of sustainable and innovative tools.

This is the context where the energy transition in our sector is taking place.

We are witnessing at a global level a progressive process of replacing energy production from fossil sources with energy produced from renewable sources, thanks to a new wave of investment based no longer on incentives but on the economic competitiveness of wind and solar energy compared to traditional sources.

Faced with an increasingly clean generation, ***the gradual penetration of electricity into the energy system will allow us not only to decarbonize the historically most polluting sectors of the economy, but also to create value in new ways by offering new services to consumers.***

The electric carrier lends itself to innovative uses in residential construction, industry and transport, bringing numerous benefits in the areas of health, environment and energy efficiency. In order to achieve this outcome, the collaboration between the main actors in the transition is crucial: Institutions, business operators and consumers.

The strategy to tackle climate change, established at ***COP21*** in Paris in 2015, set clear and challenging targets to limit the temperature increase to ***1.5°C*** by providing an update of the 2030 climate protection targets by 2020. Since then, we have witnessed an ever clearer definition of decarbonization objectives in the succession of the various Conferences of the Parties: the COP22 in Marrakech in 2016, the COP23 in Bonn in 2017, and finally - for time being - the COP24 in Katowice in the 2018, which led to the creation of a "Paris Rulebook" which defines the criteria for reporting, monitoring and reviewing the commitments made in 2015.

The global commitments have been reflected in the European context with the development of the "Clean Energy for All European Package", a set of measures aimed at increasing the competitiveness of the European economic system in a view of the energy transition. For the European legislator the 2030 targets are clear and ambitious: a 40% reduction in greenhouse gas emissions (compared to 1990 levels); a 32% share of renewable energy; an improvement of at least 32.5% in ***energy efficiency.***

Italy has responded to the call for the fight against climate change by promptly redefining its energy balance on the basis of global and European decarbonization targets. We are one of the countries most oriented towards the development of a sustainable economy powered by renewable sources. In recent years we have reached about 34% of national electricity production from "green" sources and we aim to reach in 2030 ***a share of renewable energy in the electricity sector of 55.4%***, according to what is established on a preliminary basis by the ***National Integrated Energy Climate Plan (PNIEC)***, the main Italian tool for energy-environmental planning currently being defined. PNIEC sets out objectives and measures to be pursued in order to reach the environmental targets by 2030, setting a target of ***30%*** renewables on all final consumption by 2030 (of which a share of ***21.6%*** in the transport sector compared to 14% in Europe); an improvement in energy efficiency of ***43%*** compared to the Primes 2007 reference scenario[1]; a ***33%*** reduction in

1. Scenario based on the PRIMES Model, a tool for quantitative analysis tool of the European Union's energy system that simulates energy consumption and the energy supply system.

greenhouse gas emissions in non-ETS[2] sectors and the phase-out of coal-fired plants by 2025.

The Enel Group is a global leader in the promotion of a sustainable business thanks to a high level of technological diversification and the alignment of the strategic business objectives with environmental targets. Italy is at the heart of the Group's Development Plan, in fact we have planned for the three-year period 2019-2021 an increase in investment over the previous three years to develop projects closely related to the energy transition and the UN Sustainable Development Goals. These projects include: improving the resilience and quality of service of the distribution network; developing renewables, energy efficiency, electric mobility and innovative services to the customer, which plays a central role in our business. Achieving the European target of reducing CO_2 emissions between 80 and 95% by 2050 by focusing on electrification, means ***enabling the electric carrier to new uses strictly connected to the habits of energy end-users***, the main players in a sustainable and inclusive energy transition.

Our Plan for a carbon neutral Italy is based on renewable sources, smart grids, energy storage systems, demand response (mechanisms of aggregation and active management of the demand of commercial and industrial consumers). In this context promoting the use of the electric carrier in the final consumption of the residential, industrial and transport sectors is a priority to generate a virtuous circle that starts from the demand for energy and is reflected in the relative offer, stimulating its production from sources with sustainable environmental impact.

The residential and transport sectors (i.e. efficient air conditioning and water heating systems, public and private electric mobility, maritime transport) have the greatest potential for electrification, estimated to grow from 15% to 53% over the period between 2015 and 2050, while the industrial sector - already highly electrified - has an improvement range that goes from 39% to 42% in the same period. To fully develop these opportunities, it is essential for the Institutions to commit themselves to making the Country System a fertile ground for the growth of investments necessary for economic progress linked to energy efficiency and the reduction of CO_2 emissions.

Institutions play a key role in the energy transition, promoting concrete actions to combat climate change. The new sustainable energy paradigm - based on the strong penetration of the electricity carrier in final consumption - needs to be supported by the streamlining and adaptation of the authorization procedures, in order to optimize the exploitation of the electric commodity by maximizing the production and the diversification of uses, from a timely and accurate planning of infrastructure investments, digitizing the electricity grid and making it intelligent and flexible so as to act as an enabler for new innovative services, new rules and measures to increase the flexibility of the system on both the supply and demand side (such as the acceleration of electric vehicles participation in the dispatching market through the development of the "vehicle to grid", the two-way technology that allows electric vehicles to store and return energy for grid stabilization), and a new enabling framework for the development in the market of new technological solutions and applications.

Therefore, to achieve the challenging decarbonization objectives and at the same time ensuring the reliability of the electricity system, integrated planning of investments in new capacity, new resources (i.e. demand response) and network infrastructure is critical.

Electrification is the fundamental driver to reach the Italian and European decarbonization targets and Enel's projects can contribute to their achievement. In order to fully develop its potential, it is also essential that Institutions, business operators and local communities work together to find the best tools for exploiting the end uses of electricity.

2. Emission Trading System, the European Emissions Trading System to reduce greenhouse gases in energy-intensive sectors, which sets a maximum limit on the overall level of emissions allowed to all the bound subjects, and allows participants to buy and sell on a special market the rights to issue CO_2 quotas according to their needs, within the established limit. It is aimed in particular at industrial plants, the sector of electricity and thermal energy production and air operators.

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