Energy Strategy Reviews 41 (2022) 100844

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.elsevier.com/locate/esr

Integrated energy planning to meet 2050 European targets: A Southern Italian region case study

V. Battaglia [a], G. De Luca [b], S. Fabozzi [a,*], H. Lund [c], L. Vanoli [a]

[a] Engineering Department University of Naples 'Parthenope', Isola C4, Centro Direzionale, 80143, Naples, Italy
[b] Construction Technologies Institute, Italian National Research Council, Via Lombardia 49-20098, San Giuliano Milanese (MI), Italy
[c] Department of Planning, Aalborg University, Rendsburggade 14, 9000, Aalborg, Denmark

ARTICLE INFO

Keywords:
Energy planning
Smart Energy system
Energy Transition
Energy Planning

ABSTRACT

The Campania Region has one of the highest renewable energy potentials in Italy. Despite this high potential, the lack of an integrated energy strategy has allowed for deregulated exploitation of the resources of the territory, e.g. surplus of wind energy occurs in Campania due to the large wind farms, geothermal energy is mainly used for thermal baths but its enthalpy could meet domestic heating demand, etc. A lack of an "integrated planning", does not to make the best use of resources and to contribute to greenhouse gas (GHG) emission reduction.

The aim of this work is to develop a possible scenario for achieving sustainable energy condition towards decarbonization in the Campania Region. The 2030 'transition scenario' is characterized by a reduction in GHG emissions. In the 'Campania 2050' scenario, the region's energy system is mostly reliant upon biomethane and other local renewable resources. The new methodology, based on the classification of climatic zones, was designed to meet the hourly energy and production demands of both current and future energy plants in the territory. Different software tools were used to find a new integrated renewable energy system for Campania. The software EnergyPLAN was used to design the entire system and assess the integration of the different sectors (electric, thermal, and transport), and TRNSYS 17 and DesignBuilder were used to achieve the desired hourly energy production of individual plants.

The results obtained show that the 2030 'transition' scenario is characterized by a reduction in the "1990 CO_2 emissions" of approximately 45%.

The 'Campania 2050' scenario achieves the decarbonization objective of reducing the GHG emissions by 80% with respect to the 1990 values by combining different energy efficiency strategies, relying upon renewable energy sources, and electrifying the transport sector.

1. Introduction

Many 'case studies' [1] illustrating the challenges of achieving a 100% renewable energy system have been presented to the scientific community over the last two decades. The European 2020, 2030, and 2050 energy targets [2], energy securities of the involved countries, and climate change [3] have been strong motivators in this research area. Generally, the papers in the literature focus on the role of a specific local energy resource that is widely available in the territory under investigation [4]. What clearly emerges from the literature review is that using a single versatile resource and overlooking the 'cross-sector' and 'vector' approaches to energy management in a territory do not allow that territory to achieve decarbonization [5,6,97].

To avoid ineffective scenarios, the authors took into account multiple widely available resources of the Campania region, the territory to design a smart energy system, that improves upon the current system and can be implemented in the foreseeable future. For this reason, energy resources such as those involving waves, tides, or enhanced dry rock geothermal energy were not considered in this paper.

Biomass, being a more versatile resource and largely present in the Campania Region [7], is most suitable for these hybrid energy systems and can be used in several ways: to produce biogas/biomethane using gasification or anaerobic digestion, to supply both individual thermal plants and district-wide heating systems, to feed the transport sector,

* Corresponding author.
E-mail addresses: vittoria.battaglia@uniparthenope.it (V. Battaglia), deluca@itc.cnr.it (G. De Luca), salvatore.fabozzi@collaboratore.uniparthenope.it (S. Fabozzi), lund@plan.aau.dk (H. Lund), laura.vanoli@uniparthenope.it.it (L. Vanoli).

https://doi.org/10.1016/j.esr.2022.100844
Received 23 July 2020; Received in revised form 16 February 2022; Accepted 31 March 2022
Available online 13 April 2022

etc.

The scientific literature has shown that obtaining biomethane from biogas is a sustainable way to achieve decarbonization and reduce cost. In Ref. [8], the 2030 Colombian energy system scenario, in which biomethane production, biomass-based powered generation, and wind and solar power were proposed for electricity production, achieved an approximate 20% reduction in both CO_2 emissions and total fuel consumption.

In [9], an analysis of the Danish energy systems model that estimated different CO_2 costs was performed. It was found that when biomethane was the primary fuel, the costs for systems with a high CO_2-cost diminished.

In [10], a scenario, in which biogas, biomethane, and electromethane replaced dry biomass-derived fuels in different energy sectors, was developed and resulted in a 16% reduction in the use of dry biomass along with significant energy system cost reductions.

In this paper, the authors examined the reduction in GHG emissions that is achieved when biomethane is integrated into the Campania Region energy system, when this latter is powered also by wind and solar energy. To carry out this analysis, first, the use of wind and solar energy to fuel the electrification of several different energy systems and the use of the geothermal energy for heating purposes was investigated [11–13], and then a deep biomass integration analysis was carried out.

Biomass residue is generally produced in large amounts in the south of Italy on dairy farms whose milk is used to make cheese.

In the present work, however, the authors evaluated the ability to produce biomethane from biogas not only from residual biomass but also from designated agricultural crops that are grown on marginal lands whose soil is subjected to erosion, contamination, and salinization. Marginal lands are not appropriate for primary food production [14–16], hence the choice of grow energy crops allows environmental benefits [17,18] a and efficient energy production through the Anaerobic Digestion (AD) [19].

Another form of waste biomass, highly treated in AD plants can be found in municipal organic solid waste [20].

Once the energy resources are defined for Campania Region, to determine the appropriate size of the plants and their management strategy, the authors focused on system optimization. Some scientists base their approach on economic criteria, while others consider CO_2 emissions reduction [21] and/or develop innovative ways to ensure the sustainability of resource exploitation [22]. In this study, the authors chose to focus on CO_2 emission reduction.

Different tools can be used in the design process to simulate current and future scenarios. Currently, the common trend is to adopt a "hour-by-hour" simulation approach, because a hourly simulation allows the researchers to better address the hourly behaviour of the energy system under investigation [23]. This aspect is most important for the renewable energy sources (RES) that are generally fluctuating. Therefore, the use of software tools allowing a dynamic analysis of the energy system becomes necessary in this type of study.

EnergyPLAN [24], Times [25], EnergyPro [26], MODEST [27], and PRIMES [28] are examples of the tools available in the scientific community that address multiple issues related to integrating renewable energy sectors and technologies. Generally, energy planning software provide the possibility to include the following elements: energy resources, energy services, demand sectors, thermal/electric generation, renewable generation, conversion-storage and economic parameters. However, the appropriate energy tool to be used for planning is highly dependent on the specific objectives that must be fulfilled [29].

EnergyPLAN was chosen because it has the widest range of simulation possibilities, thus allowing flexibility in its use and because it is the most complete for the evaluation of economic parameters [30], able to highlight the role of biogas production by integrating the different sectors and technologies and showing their synergy.

To obtain the hourly thermal energy demand curves of Campania to input in EnergyPLAN, a new methodology based on the classification of climatic zones was applied. This kind of approach is necessary when the climatic features are highly variable in the territory under investigation (such as Campania).

On the contrary, to get the hourly trend of the electric energy demand, authors have been able to rely on TERNA database [31].

Data about the power of hydro, PV, and wind plants already installed in Campania, were used to determine, through TRNSYS 17 [32], the hourly energy production. The TRNSYS 17 output has become an input into EnergyPLAN. Moreover, the energy production from the solar systems installed on buildings was simulated through DesignBuilder software [33].

Aggregated yearly energy demand and production values were also input into EnergyPLAN. The authors collected these data from a national database [34–38].

Campania in 2017 was the authors' reference scenario. The reference scenario served to validate the model. Starting from this validated scenario, each measure identified as a possible solution to make the Campania Region a zero-carbon territory was input into EnergyPLAN to evaluate the measure's effect on the regional energy balance. An economic analysis completed the evaluation of the feasibility of the final scenarios (2030 and 2050).

In the new renewable energy system proposed for the Campania Region by 2050, district heating and cooling, supplied by geothermal energy, biomass, and waste heat resources from thermal power plants, is introduced. In addition, the authors emphasized the role that biomethane from biomass can play in the decarbonization of the Campania region.

Finally, Authors have verified the integration of the plan proposed for Campania region with the national strategy. It is assessed the contribution of Campania on the national 2030 targets provided by the "Integrated National Energy and Climate Plan" (PNIEC) [39] and it is verified that no overproduction occurs in this Region to avoid a crisis of the national energy system.

The authors' ultimate goal was to develop an optimal energy scenario based on the use of a mix of RES by using a method that can be applied to other Southern Italy region with similar renewable energy potential resources for their future analysis in the electricity, heating, cooling, and transport sectors.

Its strategy represents a key point in national energy policies, and furthermore the replicability in other regions of southern Italy, that have similar characteristics, could be happen. On other word, this study could be an example for local administrations to follow a similar methodology for energy planning of their territories.

It worth to be noticed that in Italy there is the so-called "burden sharing". This decree establishes the division of national energy target, imposed by Europe, among the 20 Italian regions In this sense, each region becomes strategic to achieve the objectives of reducing pollutant emissions and increasing the use of renewable energy.

1.1. Novelty

As it is possible to note in literature there are several examples of implementation and analysis of a smart energy system [40,41], but there are no examples of a dynamic analysis involving the different weather condition for the area under study. The above-mentioned literature highlights an important gap: in all the "energy planning papers" the demand and production curves are unique for each sector and technology, respectively even if the territory is very large. Climatic conditions, instead, have a strongly influence on the demand energy but also on the production from renewable sources (for example production from solar thermal and photovoltaics, or the heat demand curve of buildings). The Campania region, for example, has four climatic zones (C and D particularly widespread, E and F less widespread) which particularly influence the demand or production curves.

The new methodology presented in this paper allows to have results that are closer to reality, as also highlighted in the validation results of the proposed model. Therefore, a correct energy strategy and planning cannot ignore such difference, even more in territories like Campania region and Italy, where there is a strongly variability of the climatic zone.

To overcome the lacks in the literature, this paper presents a new approach to energy planning considering a comprehensive analysis of the climatic zones. To gain a better understanding of the new approach and order to verify the robustness of the novel methodology, authors carried out a deep analysis of an Italian South region: the Campania Region. The scheme below (Fig. 1) summarises the all steps followed during the analysis: from the data collection of the “aggregated value” to the reconstruction of the hourly load demand and production energy curves through tools like TRNSYS 17 and DesignBuilder, steps necessary for building and validating a Reference Scenario; from Reference Scenario to the “planning section” with simulations of the whole energetic system of Campania by integrating different RES sources, to finish to assess of the future scenarios through parameters like Primary Energy Supply (PES), CO_2 emissions etc.

2. Campania energy system

2.1. Overview of the territory features

Campania is a region located in Southern Italy. With a population of 5 839 034 (mostly located on the coastal zone) it is among the first most densely populated region in Italy [42]. As reported in Fig. 2, obtained with a GIS analysis carried out by the authors, it is possible to figure out 4 climatic zones (C, D, E, F). According to the [43], Italy is divided into six climatic zones based on the energy consumption necessary to maintain a comfortable temperature inside the building equal to 20 °C. The ’’Degrees-Day (DD)’’ is the parameter used to differentiate the six climatic zones, it is the sum extended to all days in a conventional annual heating period of positive differences between interior temperature (conventionally fixed at 20 °C) and the mean daily external temperature. The “F” zone is the coldest area with DD > 3000.

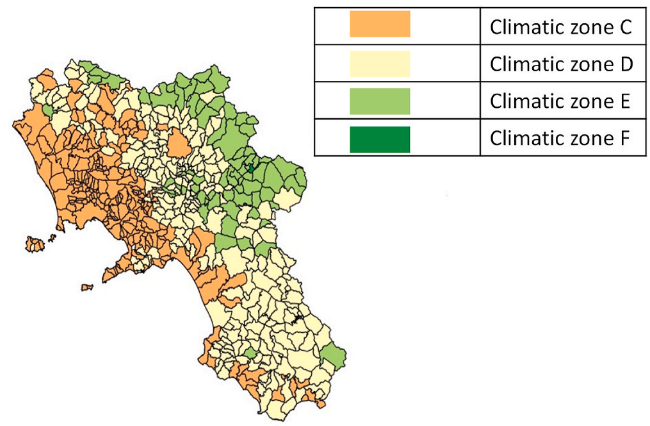


Fig. 2. Climatic Zone of Campania region.

In Campania, although the climate is typically Mediterranean along the coast (C area), whereas in the inner zones it is more continental (D-E-F areas) with low temperatures in winter (Fig. 2).

2.2. Energy balance of the Campania Region

Fig. 3 shows a Sankey diagram used to illustrate the flows of energy in the Campania region in 2017 [44]. In particular, the energy demand of and primary energy supply to the Campania system are shown. It is noted that the transport, heat, and electricity demands are not connected. Thus, it is possible to state that the current energy system is not flexible, and an increase in the production of energy from renewable energy resources could lead to a Critical Excess Production of Electricty (CEEP). A CEEP event occurs when the amount of electricity produced exceeds the electricity needs and interconnection capacity of the system.

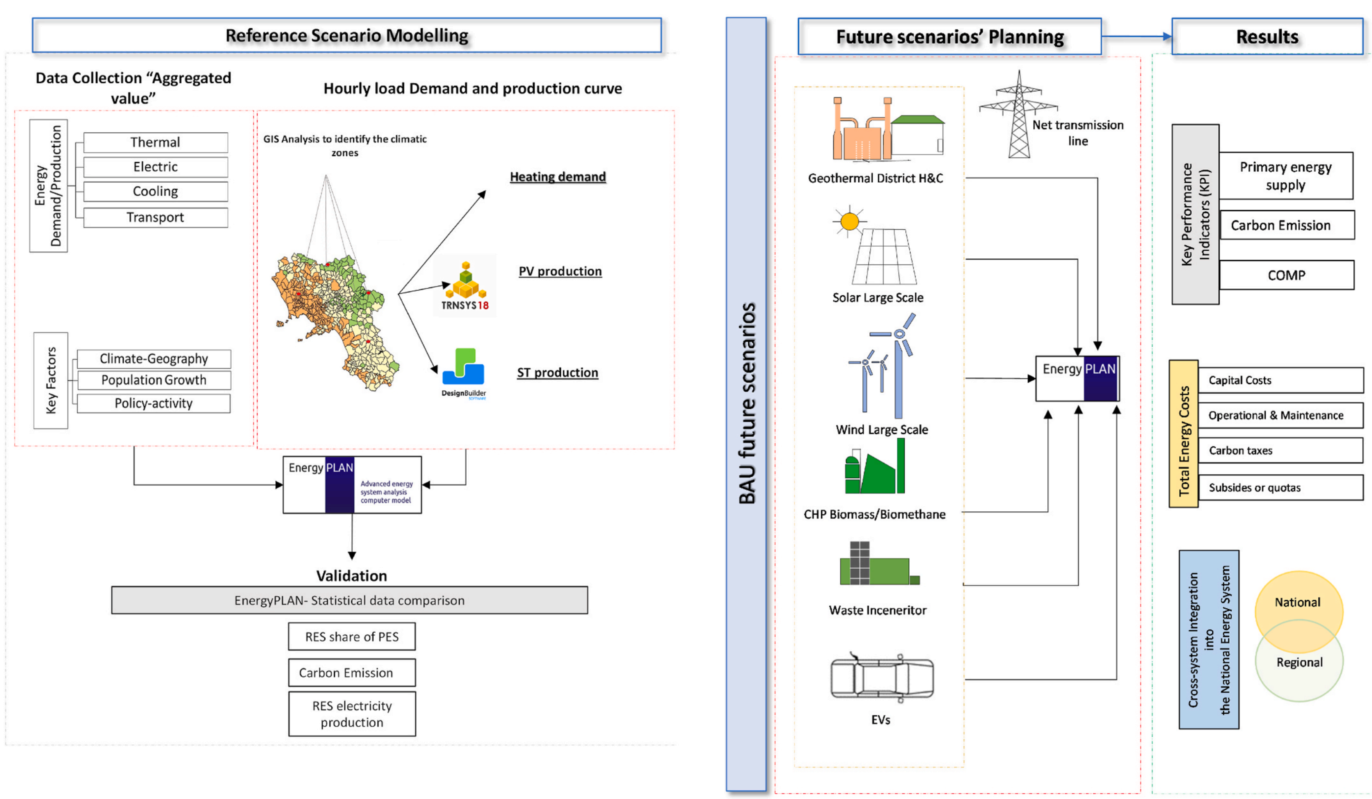


Fig. 1. Methodology scheme.

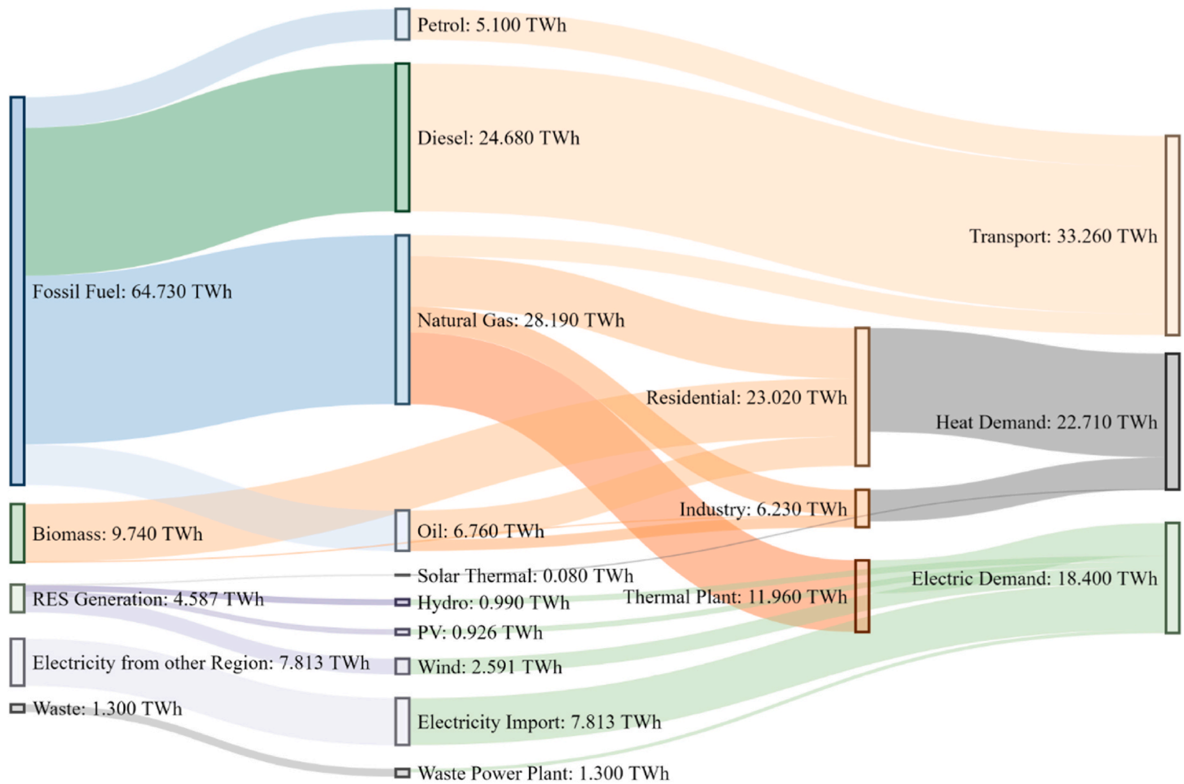


Fig. 3. Energy Sankey diagram of the Campania Region in 2017.

The CEEP scenario must be avoided so that the electricity system does not collapse [45]. Moreover, CEEP leads to a significant increase in the total cost of the production system [46].

It can be noted that districts heating and cooling, which are the most flexible sectors of the energy system, are not present, and the residential and industrial heating and cooling demands are provided by individual plants. The heating demand, which is mainly supplied by natural gas, biomass, and oil, accounts for 22.71 TWh_{th}. The use of geothermal resources is negligible, despite the fact that Campania possesses a high geothermal potential due to the presence of the vulcan Vesuvio and the caldera area of "Campi Flegrei".

The electricity for cooling, generally a negligible amount of the total energy used in many European regions, accounts for approximately 10% of the heating budget in Campania (or approximately 2.11 TWh_e) and represents 30–70% of the heat budget in the 2050 scenario, owing to increases in the standard of living and the effects of climate change [47].

The electric energy production is mainly based on:

- Conventional thermal power plants (approximately 62.7%) [31];
- Wind (approximatelyt 23.3%) [31];
- Hydroelectric (5.6%) [31];
- Photovoltaic (8.3%) [31].

Over the last 15 years, the energy production from RES, such as wind energy, has become important in some sectors. Until 2017, 593 wind turbine plants, with a power capacity of 1388 MW_e, have been installed. The installed production capacities of photovoltaic plants, bioenergy sources, and hydro plants were 784 MW_e, 233 MW_e, and 337 MW_e, respectively.

By the end of 2017, in the Campania Region, there were a total of 31 056 RES power generation plants, with a total capacity of 2741 MW_e. RES plants were responsible for 4,578 TWh_e of electricity [35].

In 2017, the total power capacity of RES plants in Campania was approximately 5% of the national power capacity. Campania was the eighth Italian Region in terms of energy production by renewable resources, with almost 28% of the total production of the south and islands (7 Mtep) [34]. More details on the Campania Energy System can be found in Tables 1 and 2 reported in the Appendix section.

3. Method

After supplying the necessary input data and assumptions (Section 3.1), the authors defined a reference scenario (Section 4.1) using EnergyPLAN software integrated with TRNSYS 17 and DesignBuider. Once the reference scenario was validated by comparing the modelled results with the statistical regional data of 2017 (Section 4.1), the authors modelled one short-term (Section 4.2) and one long-term model scenario (Section 4.3) using EnergyPLAN. The short-term scenario was called the 'transition scenario'. It allowed the authors to verify that the 2030 European objectives can be achieved via this strategy. The 2050 Scenario (long-term) was developed with the goal of reducing the GHG emissions by 80% with respect to 1990 values. In this scenario, the available RES sources are first used. After that, biomethane is integrated into the energy system.

To summarise, the authors modelled three different scenarios:

1. A reference model based on Campania in 2017;
2. The 2030 Scenario ('transition scenario');
3. The 2050 Scenario.

3.1. Input data and assumptions for the reference model

To obtain the annual energy demand/production of Campania, the regional data from 2017 were used (see Appendix 1).

Methods used to get hourly energy demand and production curve are described in the following sections.

3.1.1. Hourly electric distribution curve

The yearly value of the electric consumption necessary of the case

Table 1
Number of citizens for each climatic zone.

Zone	Number of citizens
C Zone	3 094 670
D Zone	2 452 380
E Zone	291 950
F Zone	522

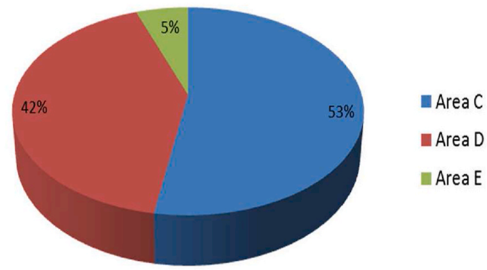
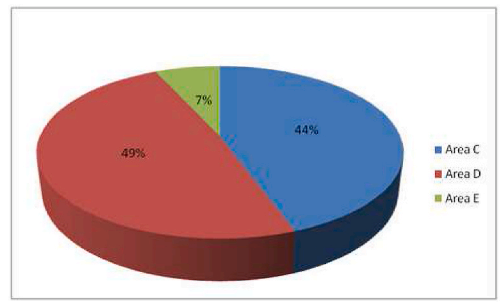


Table 2
PV Power Capacity for each climatic zone.

PV Power Capacity (MW_e)		Weight Factor
C Zone	383.87	0.44
D Zone	366.20	0.47
E Zone	51.61	0.07
F Zone	0	0



studies under investigation has referred to the data provided by Terna S.p.A [48]. and by Energy Statistics Department of MISE [49].

In order to achieve hourly energy demand, the authors used data provided by the company GME [50]. GME provides the values of electricity demand for various areas of Italy: Centre North; Centre South, North, South, Sardinia and Sicily. Authors referred to the South Centre, where Campania is located taking hourly data from February 2016 to February 2017. Fig. 4 shows the Hourly distribution demand curve in Italy (South-Centre). It is worth to be noticed that, since in Italy the cooling demand is currently supplied by electric energy, the electric curve takes already into account the electric cooling demand.

3.2. Hourly thermal energy distribution curve

As anticipated in the novelty section, a new methodology to obtain the hourly thermal energy distribution curve is developed in this work.

The hourly trend of thermal demand (Fig. 5) has been calculated as a function of the outdoor temperature and the number of people for each area.

The hourly temperature of Naples, Rome and Potenza (the latters are

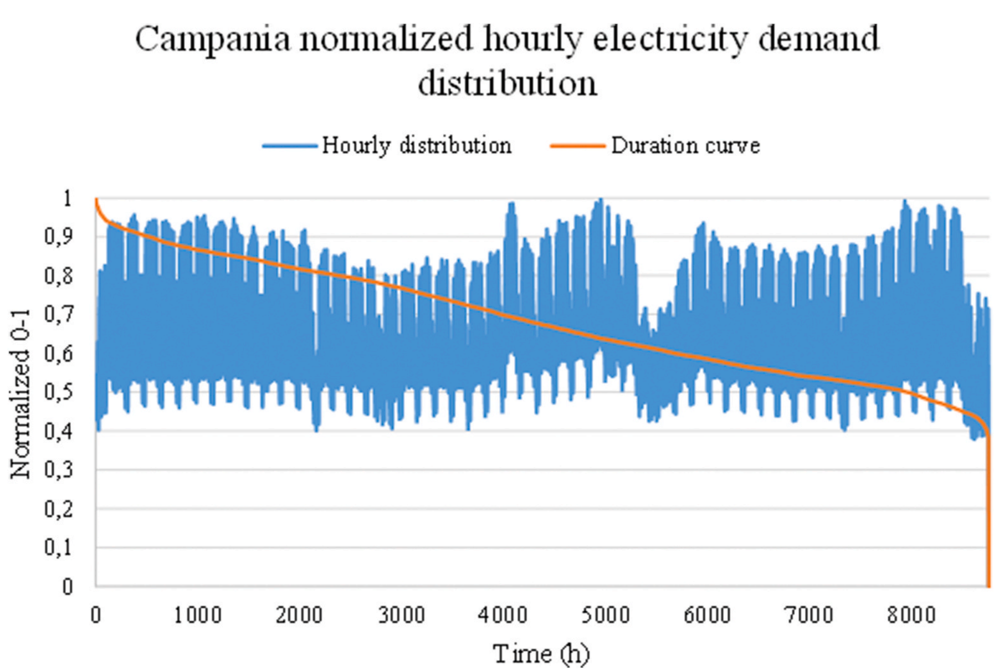


Fig. 4. South-Centre Italy hourly electricity distribution.

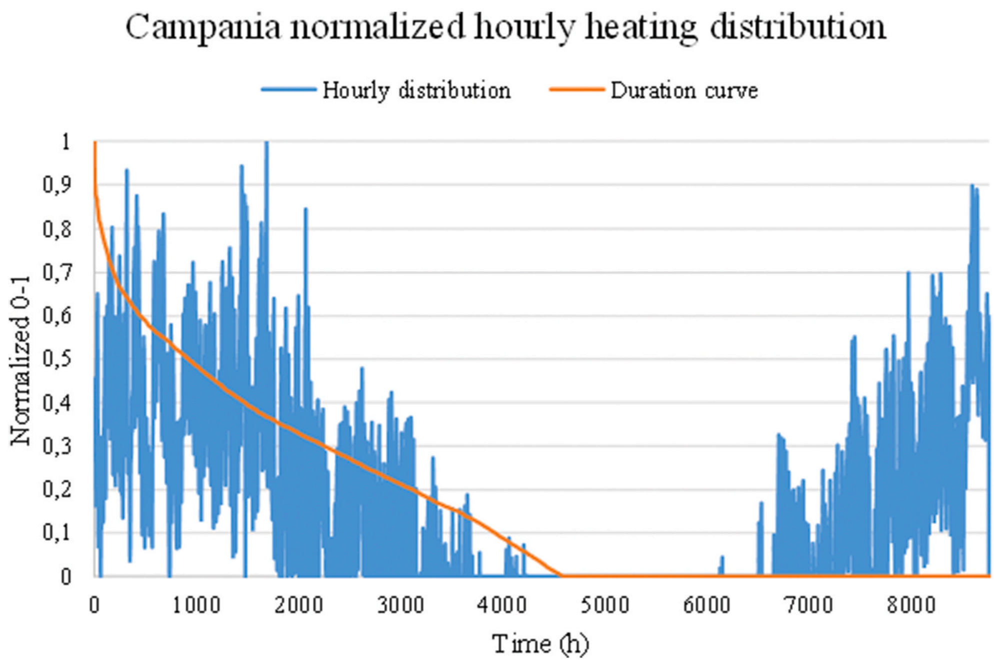


Fig. 5. Campania hourly heating distribution.

not in Campania but their climate is similar) [51] was used in order to reproduce the temperature trends of climate zones C, D and E, respectively. Moreover, the number of people living in each zone was calculated (Table 1) by ISTAT data [52]. The number of citizens of zone F does not affect significantly the total amount (0.05%), therefore it was neglected.

3.3. Hourly cooling energy distribution curve

The cooling demand trend was calculated using the same methodology used for the heating demand. In this case, the sol-air temperature was considered instead of the air outdoor temperature. The sol-air temperature is defined as the equivalent outdoor air temperature that provides the same rate of heat transfer to a surface, as would the combination of incident solar radiation, convection with the ambient air and radiation exchange with the sky and the surrounding surfaces [53]. The cooling plants are considered turned off when the sol-air temperature is lower than 28 °C.

3.4. Reference hourly electric energy production by PV plants

Following the standard heating demand methodology, the PV hourly energy production was calculated for three climatic zones, C-D-E, corresponding to Napoli, Rome, and Potenza, respectively. The PV plants' outputs (gross area of collector equal to 1.00 m^2) were simulated by TRNSYS 17 software [54,55] using the weather data from each of these zones.

From Fig. 6, which shows the yearly electric energy production of the PV plants in each climatic zone, it is evident that the PV production varies among the climate zones.

Once the hourly energy production data were obtained, they were multiplied by the weight factor (Table 2). The weight factor was

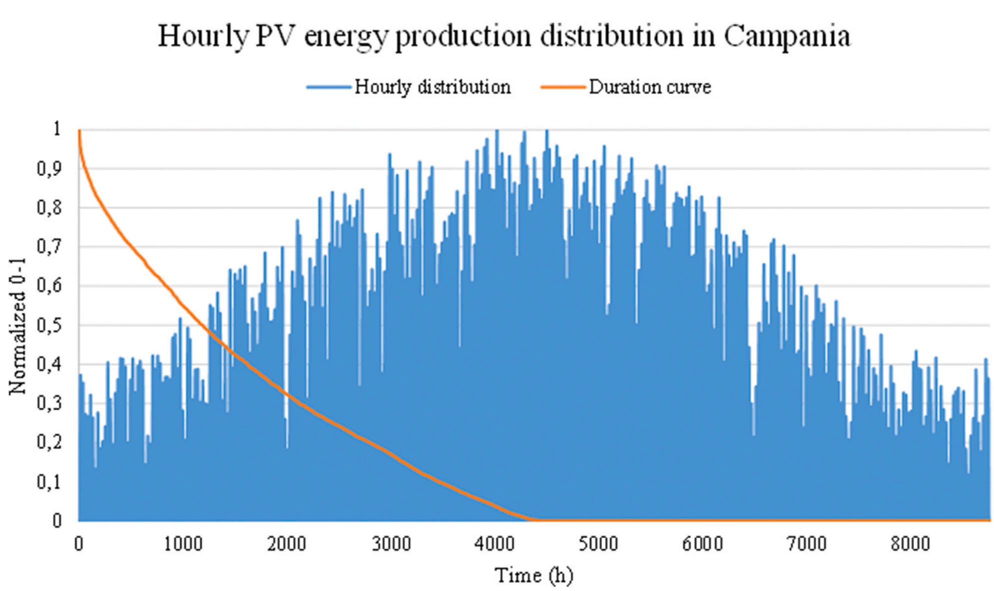


Fig. 6. Hourly PV energy production distribution in Campania.

calculated based on the PV plants' power capacity in each climate zone [35].

3.5. Thermal energy production by solar thermal collectors

The hourly thermal energy production by solar collectors was determined using the DesignBuilder software [33]. An individual solar thermal system with solar panels with an area of 4.40 m^2 and a 200 L storage tank was simulated. The energy production from a solar panel was based on a daily consumption of 1.05 L/(m^2 d) per flat, which is typical for the Campania Region (flats were assumed to be 110 m^2 in size with four inhabitants). The water temperature ranged from 15 °C to 55 °C and was only used for sanitary purposes. The solar contribution to space heating was not considered.

Using standard heating demand methods, the total solar thermal energy production was calculated for the three climatic zones.

Next, the total solar collector surface area was calculated for each climatic zone (Table 3) to obtain the weighted average of the hourly thermal energy production in Campania.

The hourly trends were input into the EnergyPLAN software.

3.6. Electric energy production by wind and by hydropower and, the transportation energy demand

The details related to the other curves needed for the refence scenario have been inserted in the appendix (Figs. 1, Figs. 2 and 3 of the appendix), where can been found the Electric energy production by wind plants, the electric energy production distribution by hydropower and the transportation hourly curve demand.

4. Outlined scenarios

4.1. Results and validation of the 2017 reference scenario model

The 2017 scenario served as a starting point for the future scenarios.

To validate the model, typical parameters were used to validate the EnergyPLAN scenario [56] (CO_2 emissions, RES share of PES, and RES electricity production). The electric energy data were obtained from that of RES and CO_2 emissions. The authors did not include the non-organic solid waste used in incineration plant in the RES contribution. As noted, the discrepancy between output and real data is very limited (Fig. 7), allowing the authors to conclude that the reference model accurately simulated the Campania energy system and could be used with confidence to build future energy scenarios.

However, the production from other technologies could be either lower or higher than these values. Therefore, it was possible to specify a correction factor to adjust the hourly distribution input for the renewable resources (use of this factor did not change the power output at full-load hours or at hours of zero output).

4.2. Scenario 2030

A scenario that models the transition towards the decarbonization of the Campania region was developed and was called the 'Transition Scenario'.

Firstly, the energy demand in 2030 was determined based on the following:

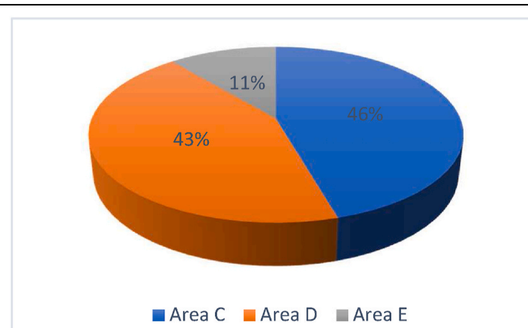
- The methodology used to predict the electric demand for the Campania Region in 2030 was the same employed by TERNA to predict the energy demand. The drivers used were the population and Gross Domestic Product (GDP). The electricity demand computed by TERNA had an average annual increase of 1% for Central-Southern Italy, ranging from an electricity demand of 18.4 TWh_e/year (in the 2017 reference scenario) to a value of 19.34 TWh_e/year in 2030 [57];
- Heat demand for domestic hot water (DHW) was assumed to be constant, because an efficiency improvement does not significantly affect the energy demand [58];
- Conversely, due the improvements in the energy efficiency of buildings and plants, the heat demand decreased by 33% [58];
- The energy required for cooling, as predicted by HRE3/STRATEGO [47], increased by 20%, from 2.69 TWh/year (2017) to 3.2 TWh/year;
- Electrification of the transport sector through the use of electric and hybrid vehicles and vehicle to grid (V2G) technology [59] was predicted. In response, less diesel was consumed (4.11 TWh/year), and this energy source was replaced by electric power, resulting in a loading-unloading curve (smart charge). Diesel consumption dropped from the 2017 value of 24.68 TWh/year to 17.59 TWh/year [60]. The efficiency of the electric vehicles was assumed to be 6.4 km/kWh_e [59];
- The LPG consumption was replaced by that of natural gas, which increased from 2.27 TWh/year to 5.05 TWh/year [60];
- The industrial energy consumption decreased due to an increase in the efficiency of the various technologies and the use of furnaces.

In addition, it was predicted that by 2030, the main energy companies will have introduced new technologies into the energy system of Campania:

- The power plant capacity will be reduced by approximately 50% with respect to 2017 (from 2,134 MW_e to 1,040 MW_e) with the addition of combined heat and power CHP plants [31];
- The grid stabilization share for the power plants will be 650 MW_e;
- A potential expansion of the wind energy will engender a capacity of up to 2,000 MW_e [61];
- A potential expansion of the PV sector will lead to an increase of capacity up to 873 MW_e [44].

Table 3
Average surface area of the solar thermal collectors in each climatic zone.

Solar thermal collectors surface (m^2)	
C Zone	22 345.18 m^2
D Zone	21 279.33 m^2
E Zone	5449.03 m^2
F Zone	28.64 m^2



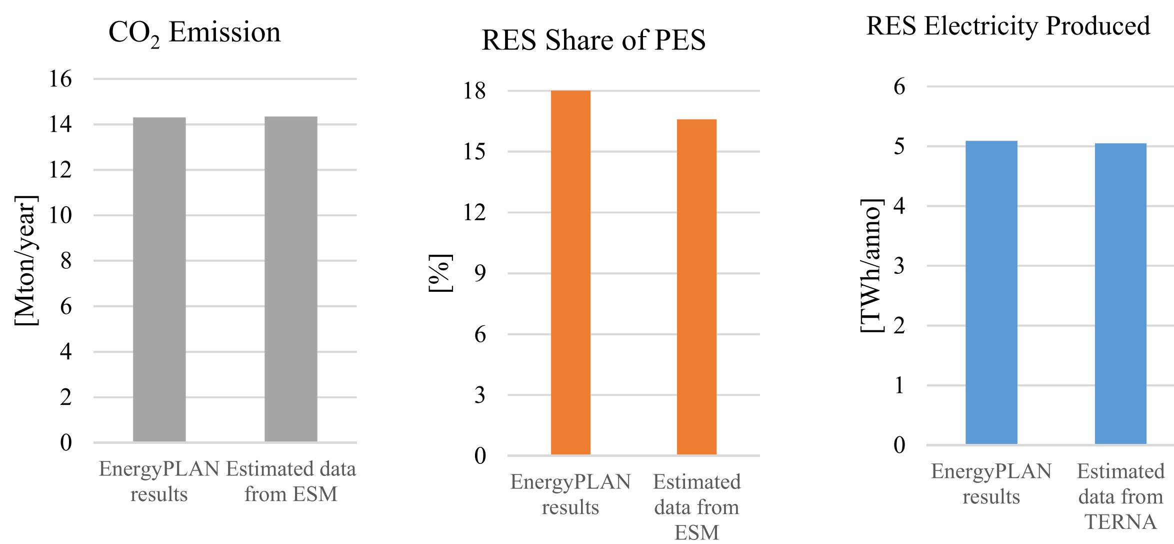


Fig. 7. EnergyPLAN outputs for the 2017 scenario versus database data: a) CO_2 emissions, b) RES share of PES, and c) RES electricity production.

Assuming these forecasts, it was possible to define a 'BAU scenario 2030' that is quite different from that obtained using the energy strategy imposed by the EU and that is characterized by a CO_2 emission equal to 14.18 Mton (Fig. 8).

To reduce the CO_2 emissions, the authors introduce a district heating and cooling (DHC) systems in order to decrease the use of fossil fuels, since they can use waste heat and renewable energy sources as geothermal and solar sources.

In Campania, a geothermal potential assessment was developed in several studies based on the VIGOR project [62]. For example, in the northern zone of Campi Flegrei, the geothermal well temperatures are around 100 °C at very shallow depths (hundreds of metres) [63], while the enthalpy from the geothermal activity below the Ischia and Capri islands is at a medium level (Table 4 of the Appendix). In the Vesuvius area, the recorded temperatures in the wells are very low (51 °C at a depth of 2,071 m).

The heat flow variation in the Campania region led the authors to design a Multi-Level District Heating (MLDH) system [64], in which thermal energy was supplied through pipes that were at different temperatures. Geothermal energy was used to power the absorption machines, whose pipes were maintained at a temperature of 80 °C, while the adsorption machines were maintained at a temperature of 55 °C.

After an assessment of the available geothermal resources, it was forecasted that 50% of the residential sector's thermal energy demand would be satisfied by individual plants operating on natural gas. The remaining 50% would be satisfied by geothermal energy. The total thermal demand attributed to the district heating network was 6.78

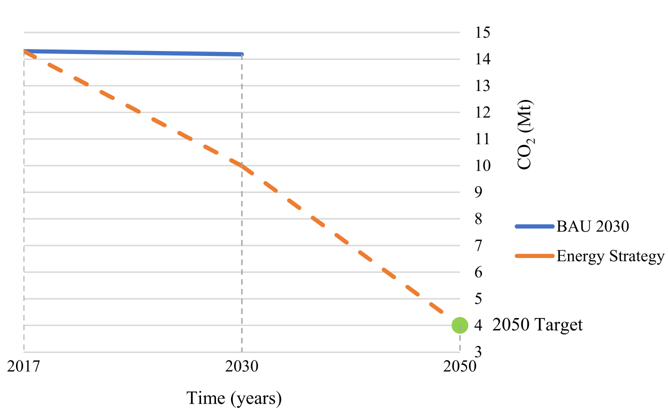


Fig. 8. CO_2 emission in BAU 2030 scenario and 2050 energy strategy.

Table 4
Electricity demand, electricity supply, and fuel consumption, sorted by technology.

TWh/year	2017	2030	2050
Electric Demand	18.4	19.34	21.07
Electric production from technology			
Traditional Power Plants	5.46	4.91	2.64
CHP Plants	0.22	3.71	1.54
Waste Plants	0.55	0.84	1.75
RES	4.54	5.25	21.31
Electric consumption by fuel			
Traditional Power Plants			
Ngas	12.13	10.91	3.41
Oil	0		
Biomass		0	1.32
Biogas	0	0	0
CHP plants			
Ngas	0	2.32	1.18
Biomass	0	2.32	0
Biogas	0	0	0.5
Waste Plants			
Waste	1.75	1.75	2.58

TWh/year, with an 18% loss. The total demand was 7.98 TWh/year. The data related to the technologies used and the resources to supply the district heating and cooling network hypothesized at 2030 can be found in Tables 4 and 5 of the section "Results and Discussion".

4.3. Scenario 2050

To achieve the 80% reduction of GHG emissions by 2050 with respect to the 1990 values in the Campania Region, the authors implemented several changes on both the demand and supply sides of the

Table 5
Heating and cooling demand forecasting.

TWh/year	2017	2030	2050
Heating Demand	17.05	13.06	11.11
Individual Heating Demand	17.05	6.28	4.45
District Heating Demand	0	6.78	6.66
Heating Demand Covered by District Heating (%)	0	52	60
Cooling Demand	2.69	3.2	4.43
Individual Cooling Demand	2.69	2.11	1.4
District Cooling Demand	0	1.09	3.03
Cooling demand Covered by District Cooling (%)	0	33	68

energy system. Following the protocol used to develop the 2030 scenario, an assessment of the energy demand was first carried out, then an analyses of the new technologies to be included in the 2050 energy system were performed.

The 2050 scenario was based on the following assumptions, while the model implemented was based on the 2030 one:

- The methodology used to predict the electric demand for the Campania Region in 2050 was the same as that used to develop the 2030 scenario [57]. The electric demand was assumed to increase to 21.07 TWh_e/year by 2050;
- According to the projections based on the residential heating data provided by ENEA, the improvements in the energy performance of buildings [65], e.g. whose defined for the NZEBs or ZEBs, and technological devices was expected to reduce the thermal energy consumption. By 2050, the total heating demand by the residential sector was expected to further decrease of 15% from the 2030 value from 13.07 TWh_{th} to 11.11 TWh_{th};
- The annual space cooling demand by the residential sector was expected to reach 4.40 TWh_{th} [66], increasing of around 35% with respect to 2030 value;
- Use of fossil fuels to satisfy industrial energy needs was predicted to decrease from that in the 2030 scenario in favor of an electrification of the sector [31];
- Electrification of the transport sector was expected to increase from 2030 levels due to an increase in the use of electric vehicles with a smart charge [31]. The total km/year driven by the road fleet was predicted to be the same [57,66]. The efficiency of the electric vehicles was predicted to be 6.4 km/kWh_e [66].

The following hypothesis were assumed:

- The total programmable thermoelectric generation was predicted to remain the same of 2030 [57];
- By 2050, the DHC would be powered by CHP plants fueled by natural gas and RES (geothermal energy from compression heat pumps and for absorption machines, solar thermal collectors [44], and biomass [67]);
- In the 2050 scenario, the installed wind capacity would be 2571 MW_e, and the PV capacity would be 1018 MW_e [68].

Assuming the aforementioned forecasts and on the basis of the assumptions about the installed technologies, the authors were able to define a 'BAU scenario 2050' that was characterized by a CO_2 emission equal to 7.20 Mton. However, this scenario did not meet the EU objectives (Fig. 9) (see Fig. 10).

A higher capacity of RES for the electricity production was integrated for the year 2050, considering the available area in the region, for the installation of wind (up to 5200 MW_e) and PV (up to 1650 MW_e) power plants. However, the higher integration of RES considered was not sufficient to achieve the GHG reduction targets set.

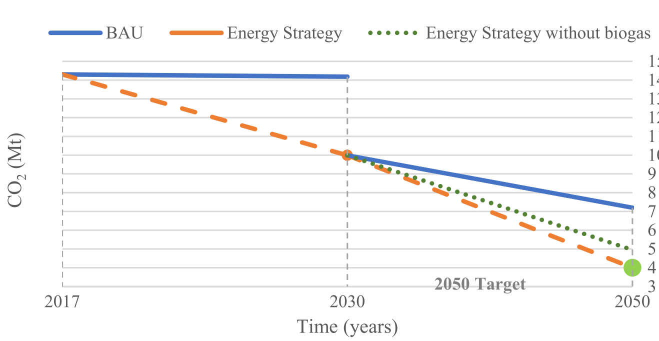


Fig. 9. CO_2 emission from the 2050 BAU scenario and energy strategy.

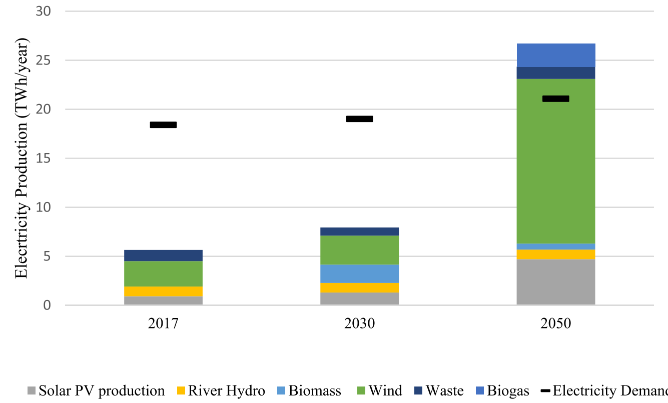


Fig. 10. RES electricity production and electricity demand.

For this reason, the authors investigated the possibility of exploiting another resource widely available on the territory: biomethane.

Assumptions about the origins of biomethane and its production were as follows:

- Biomethane was assumed to originate from the biogas upgrading process, where biogas was obtained through AD;
- The process yields used to calculate the biogas production were those of dry AD [37,69];
- The energy needs of the biomethane production process (energy to heat the digestion unit and 5% torch losses) could not be completely satisfied by biomethane itself;
- 80% of the estimated biogas production value comes from first-harvest crops (monocultures), the rest is identified as "biomass integration". The utilized agricultural area (UAA) is supposed to endure important changes in land use, due to the crisis of tobacco and erosion phenomena, already started in the reference year. According to Ref. [70], 50 000 ha was dedicated to the growth of 'energy crops.' The quantity of biomethane produced was based on the amount of land dedicated to energy crops, the yield of biomethane production from first-harvest corn, and the corn production yield per hectare of farmland. On the basis of these hypotheses, 336 million Nm^3 of biomethane was produced from agricultural land (LHV of biomethane = 9.437 kWh/S m^3, totaling approximately 3,17 TWh/year of primary energy [71]);
- Other sources of biomethane production were believed to originate from the digestion of the organic fraction of municipal solid waste and manure sludge. The value used in this work is 110 kg/year per capita of organic waste collected in Southern Italy, from which it was predicted that 684 137 tons of organic waste would be produced per year. This yielded 0.40 TWh/year of primary energy from biomethane production, assuming a rate of biogas generation of 110 Nm^3/ton, 60% of which was assumed to be methane [72];
- Considering the estimated number of livestock in Campania [73], it was assumed that approximately 80% of the manure biogas production in Campania consisted of buffalo waste [73]. The total amount (considering losses for collection, transportation, treatment of manure, and the efficiency of digestion) was 153.3 million Nm^3 of biogas/year, with a methane content of 55%. The energy contained in the biomethane from manure was then 0.8 TWh/year. Thus, it was assumed that in 2050, up to 90% of the biogas production in Campania would be due to the anaerobic digestion of veal/buffalo manure.

Hence, 4.17 TWh of biomethane would be produced in the 2050 scenario.

Table 6
Individual fuel consumption due to heating and cooling.

TWh/year	2017	2030	2050
Individual Heating Demand	17.05	6.28	4.45
Heating Demand Covered by Solar Thermal	0.068	0.018	0.043
Individual Heating Consumption (TWh/year)		**2030**	**2050**
Oil	3.41	0	0
Natural gas	8.15	2.83	0
Biomass	8.5	4.67	0
Electricity	0.02	0	0,91
Individual Cooling Consumption (TWh/year)	**2017**	**2030**	**2050**
Electricity	2.69	1.32	0.47

5. Results and discussion

This section presents the main findings from the above analysis. The first result involves the projections of the energy demand in each modelled scenario (sorted by sector), energy supply from technology, and fuel consumption (Tables 4–9).

One observes that the electric energy demand during 2030–2050 is higher than that during 2017–2030. The reverse is true for the heating demand. Moreover, in 2030 and 2050, the heating demand shifts toward district heating. The cooling demand, previously satisfied by individual plants, shifts to DHC by 2050 (68% of the total demand).

As in the reference scenario (2017), a note about the natural gas consumption in the 2030 and 2050 scenarios has to be pointed out. The role of gas-based technologies in 2017 appears to be more significant in the region's scenario, because Italy is one of the European countries that does not rely on nuclear power. Here, natural gas is the main 'stabiliser' in the electric energy balance, and hydropower (and its storage) balances the system. The high penetration of fluctuating renewable energy makes the system vulnerable, and natural gas technologies remain a 'back-up' and stabilize the electric grid.

Table 10 shows the capacities of the various technologies for each scenario. The CHP and power plant capacity decrease from the 2017 scenario to the 2030 and 2050 ones due to the increase in RES. By 2050, 10% of the installed capacity is solar PV, 31% is wind power, and 2% is hydropower.

The high penetration of RES in the 2050 scenario meets the target set for 2050: the CO_2 emissions in 2050 are 80% lower than they were in 1990 (Fig. 11).

Fig. 12 shows the primary energy supplies in the scenarios and their respective CO_2 emissions. The oil consumption decreases from the 2017 scenario to the 2050 scenario, while non-organic solid waste used in incineration plants and RES share increase.

Once the future scenarios were determined, it was important to verify the flexibility of its electric energy system. When it comes to evaluate the integration of variable renewable energy sources (VRES) fluctuations in electricity production must be considered. This is because fluctuations require more flexibility than fossil fuel-based energy systems. To do that, the authors decided to use the compromise coefficient (COMP).

According to the survey at the basis of the analysis performed in Ref. [74], the COMP factor is one of the most frequently applied criteria to evaluate the performance of energy systems. Besides the COMP coefficient, other parameters have been formulated to assess the flexibility of the system, such as:

- Relocation coefficient [75], which can compare different technology options' ability to give flexibility to the system and is defined as the "*statistical correlation between net electricity exchange between plant and system, and the electricity demand minus intermittent electricity production*";
- Flexibility factor/system flexibility defined by Refs. [76,77] as "*the fraction of peak load below which conventional generators can cycle*", which is the lowest hourly value divided by the maximum one.

However, the COMP coefficient, defined by Connolly [78], was preferred to the abovementioned parameters by the authors for two main reasons:

- It has been used in more works, [79–82];
- it assesses the optimum value for the integration of one RES introduced in the system and having a high impact on it, which is exactly what the author wanted to assess in the present work.

In [78] Conolly et al. introduced the compromise coefficient (COMP) to assess the feasible levels of wind penetration for the Ireland energy system. The COMP is the ratio between the PES gradient (ΔPES) and the CEEP gradient (ΔCEEP):

Table 7
Thermal energy demand forecasting, thermal energy supply, and fuel consumption by DHC technology.

TWh/year	2017	2030	2050
DHC Demand	0	10,18	8,4
DHC production by technology			
CHP plants	0	4.63	1.68
Solar thermal	0	0.12	0.15
Geothermal HP	0	2.83	3.16
Heat exchanger (Geothermal direct use)	0	0.51	1.8
DHC consumption by fuel			
Geothermal HP			
Electricity	0	1.48	1.55
CHP plants			
Ngas	0	2.32	1.18
Biomass	0	2.32	0
Biogas	0	0	0.5

Table 8
Fuel consumption for heat and electricity production.

Fuel Consumption for Heat and Electricity Production (TWh/year)	2017	2030	2050
Natural Gas	12.13	15.54	3.76
Biomass (including Waste and Biogas)	1.15	6.38	9.27

Table 9
Fuel consumption for the Industry and Transport sector.

Industry Consumption (TWh/year)	2017	2030	2050
Oil	1.87	1.6	0.3
Natural gas	4.43	5.18	3.3
Biomass	0.05	0.05	0.2
Fossil Fuel Transport Consumption (TWh/year)	**2017**	**2030**	**2050**
Diesel	19.65	17	0
Petrol	5.03	2	1
Natural Gas	0.77	4.5	11.5
LPG	2.71	0	0
Electricity Transport Consumption (TWh/year)	**2017**	**2030**	**2050**
Electricity Smart Charge	0	1.9	4.5

Table 10
Installed capacity of each technology and each scenario.

Technologies	2017	2030	2050
Power Plant Capacity (MW_e)	2113	650	390
Cogeneration Plant Capacity (MW_e)	147	1,040	1,300
Compression Heat Pumps Capacity (MWe)	53	1,200	450
Variable Renewable Electricity (Mwe)	2516	3,222	7,199
PV Panels (MWe)	783.8	873	1,650
Wind turbine (MWe)	1390	2,000	5,200
Hydro (MWe)	342.4	349	349

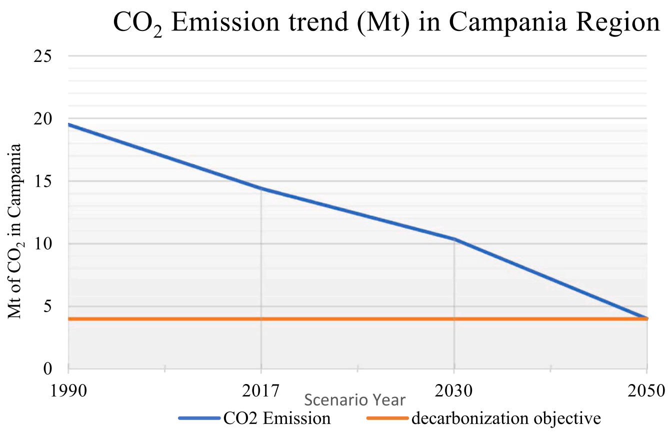


Fig. 11. Changes in the CO_2 emission.

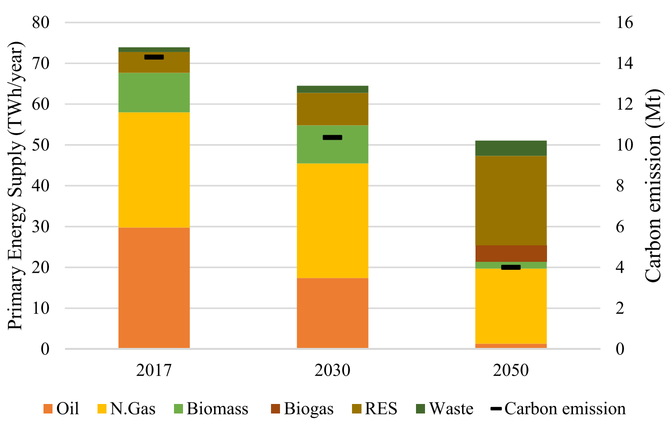


Fig. 12. Primary Energy supply in the scenarios analysed.

$$COMP = \frac{\Delta PES}{\Delta CEEP}$$

The optimum solution occurred when COMP was one, i.e., the reduction in the primary energy supply was the same as the increase in excess electricity.

In this work, however, the COMP was used for verifying the 2030 e 2050 energy systems considering the whole RES system.

Accordingly, the flexibility of the system was evaluated by calculating the PES and CEEP for the outlined scenarios using EnergyPLAN software to obtain the variation in the RES component of the electricity production. The results obtained for the 2030 scenario are listed in Table 11.

The results show that the renewable energy capacity can still be exploited without losing flexibility. The results obtained for the 2050 scenario are listed in Table 12:

It is shown in Table 12 and Fig. 13 that since the COMP value for the 2050 scenario is the closest to one (with RES share around 90%) and the CEEP is less than 10% of the total electricity demand, the new Campania energy system is highly flexibility and is characterized by integrated energy sectors and the installation of DHC.

Alternatively, hydropower, confers stability and reliability to the systems and provides storage capacity and flexibility.

Table 11
Compromise Coefficient for the 2030 scenario.

RES share in electricity production (%)	CEEP (TWh/year)	CO_2 (Mt)	PES (TWh/year)	COMP
20%	0.04	11.47	57.35	
30%	0.05	10.77	57.1	25.0
35%	0.08	10.41	56.87	7.7
40%	0.14	10.05	56.56	5.2
50%	0.47	9.76	5564	2.8

Table 12
Compromise Coefficient for the 2050 scenario.

RES share in electricity production (%)	CEEP (TWh/year)	CO_2 (Mt)	PES (TWh/year)	COMP
40%	0	9.183	34.54	
60%	0.04	6.74	32.13	60.2
75%	0.61	5.207	30.6	2.7
90%	2.09	4.009	29.51	0.7
100%	4.42	2.87	28.64	0.4

5.1. Integration of campania scenarios into the future national energy system

The aim of this section is to verify the integration of the plan proposed by the Authors for Campania region with the national strategy. It is also assessed the contribution of Campania on the national 2030 targets, and it is verified that no overproduction occurs in Campania to avoid a crisis of the national energy system.

The "Clean energy package" adopted by the European institutions sets the regulatory framework of the Union governance for the energy and climate strategy in order to achieve the new European objectives by 2030 and a low-carbon economy by 2050. In this legislative framework, every Member State had to provide a national energy plan. The Italian Integrated National Energy and Climate (PNIEC- 2020) [39] sets new targets: 30% of the final energy covered by RES. It fixed a roadmap, a policy to follow but no "actions" or a distribution of targets between the regions and autonomous provinces of Italy. According to the PNIEC "*the national programme, when approved, will be coordinated with regionally managed programmes*." In this framework, Authors outlined a strategy for Campania Region by 2030 that follows the national program.

In the 2017, Campania Region recorded a final energy consumption about of 7 Mtep, it meant the 5,8% of the whole Italy consumption. Moreover, the Campania consumption of energy by RES was of 1,2 Mtep, while Italy showed a consumption of Energy by RES of 22 Mtep; on the other hand, Campania impacts on the Italian RES consumption for the 5,5% and it shown in 2017 a ratio of consumption of energy by RES and the final energy consumption equal to the 17,1%. These values allowed to reach the "2020 burden sharing aim" for Campania provided by the Decree March 15, 2012 of MISE Ministry with three years in advance; however, the contribution of Campania becomes more significant with the implementation of the strategy presented by the Authors.

In 2030, Campania could affect the Italian Energy Balance for 5,9% and 5,1% on the value of the RES consumption and the final energy consumption Fig. 14. It is important to notice that in RES, only the 50% of energy carried out by the waste has been considered as indicated by the Italian Minister Decree [49].

About the electricity sector of Italy, in 2017, approximately 35% of gross national production originated from RES; the renewable source that made the greatest contribution to actual electricity production in 2017 was hydropower (35% of overall electricity production from RES), followed by solar power (23%), bioenergy (19%), wind power (17%) and geothermal power (6%). The PNIEC is mainly focused on PV and wind plants increment for Italy by 2030 (Fig. 15 (a)). It provides the 62% and 49% growth in the power installed and the 67% and 59% growth in the electric energy production for PV and wind plants respectively, (Fig. 15(a)). The Campania strategy follows the Italian one by presenting an increment of energy production by PV and wind plants equal to 80% and 86% respectively. Once the Campania plan will be implemented, the Region will boast a predominant component of wind energy production in its energy balance. The impact of the Campania strategy on Italy RES energy production is shown in Fig. 16. In 2030, Campania Region will

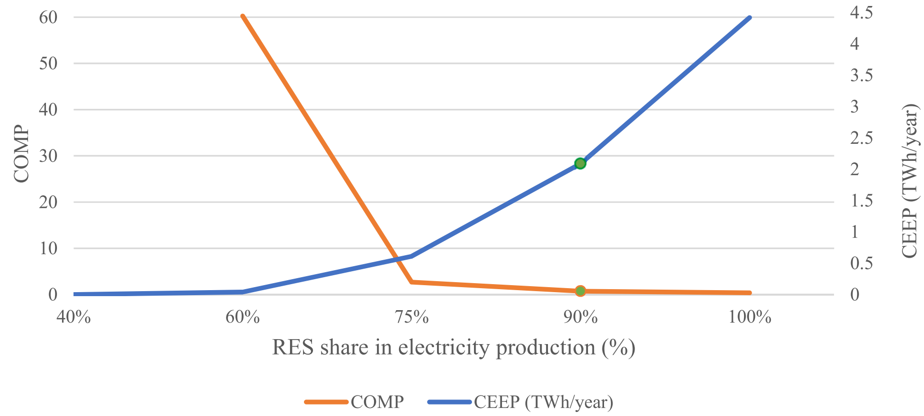


Fig. 13. Comparison COMP and CEEP.

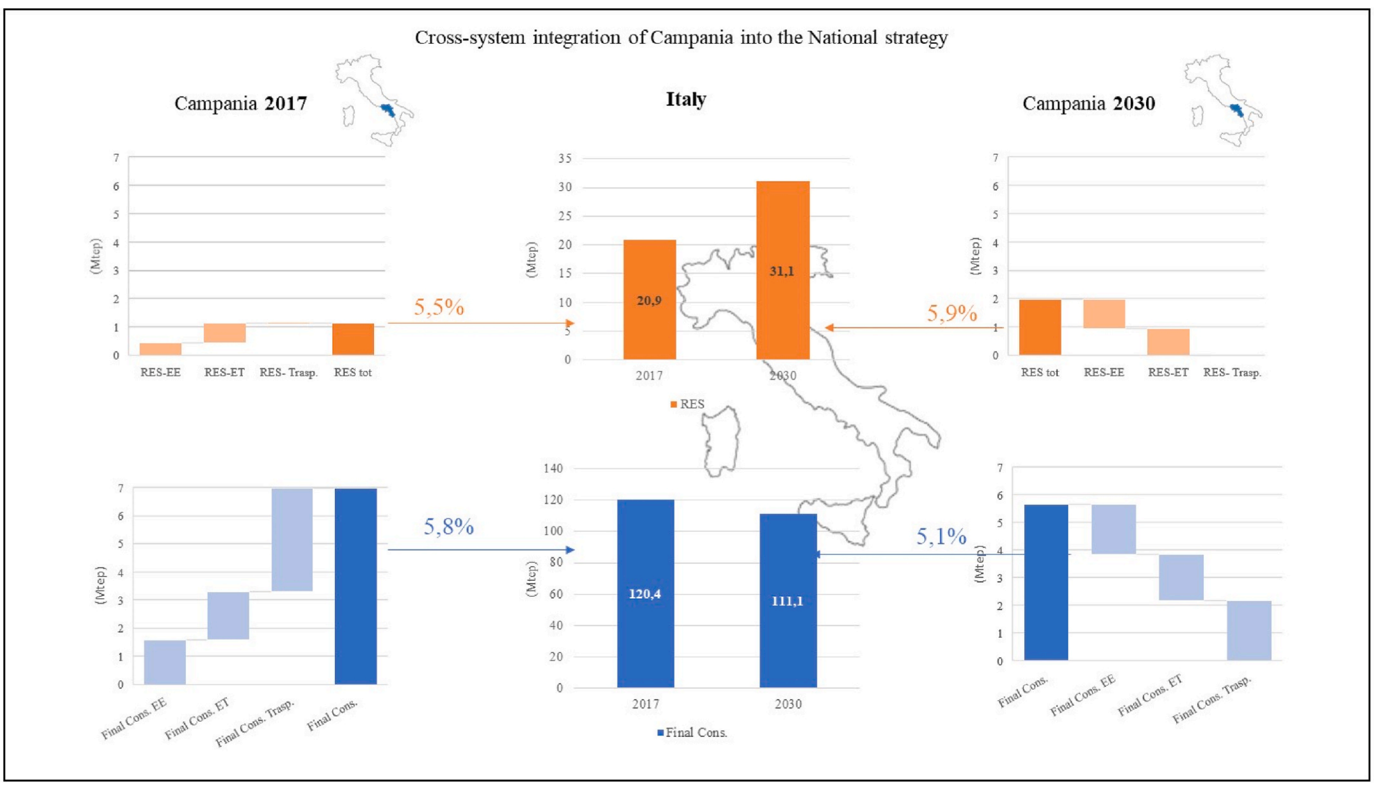


Fig. 14. Cross-system integration of Campania into the National Strategy.

contribute with the 40% to the national wind energy production and with the 16% to the national bioenergy production.

Moreover, the PNIEC encourages the developing of the efficient district heating and cooling filled by RES and by the energy recovered from waste and biomass to reduce emissions. Authors have fulfilled the PNIEC strategy by including geothermal district heating and cooling systems. The DHC is dedicated to the geothermal energy exploitation that is neglected so far even if it is characterized by zero GHC emissions.

6. Cost analysis

In this section, a rough analysis of the costs associated with each scenario is given. The investment and operating/maintenance costs were estimated using data from the scientific literature. In this work, only the additional investment costs are considered in the economic analysis. In fact, the analysis involves verifying the feasibility of the changes in the energy demand and energy system infrastructure. Additional investment costs are also those associated with the renovation of the plants at the end of their operating life. The 2017 costs involve only the operating and maintenance costs as well as those required to replace the natural gas boilers (as they already have a long lifespan). In Table 3 in the Appendix, the investment costs and Fixed operating and maintenance for the introduced technologies are shown.

The costs vary based on the reference year for each scenario. The determination of the costs associated with the EV infrastructure required computing the percentage of electric vehicles used in each scenario. The costs of the EV charging stations are expressed in the form of a linear dependency between the EV penetration and the annual costs associated with the EV charging infrastructure as follows [83]:

$$CEV_{infrastructure} = (24.89 \text{ x } EV_{share} + 78.5).\text{M€}$$

The total annual costs of the energy system include those associated

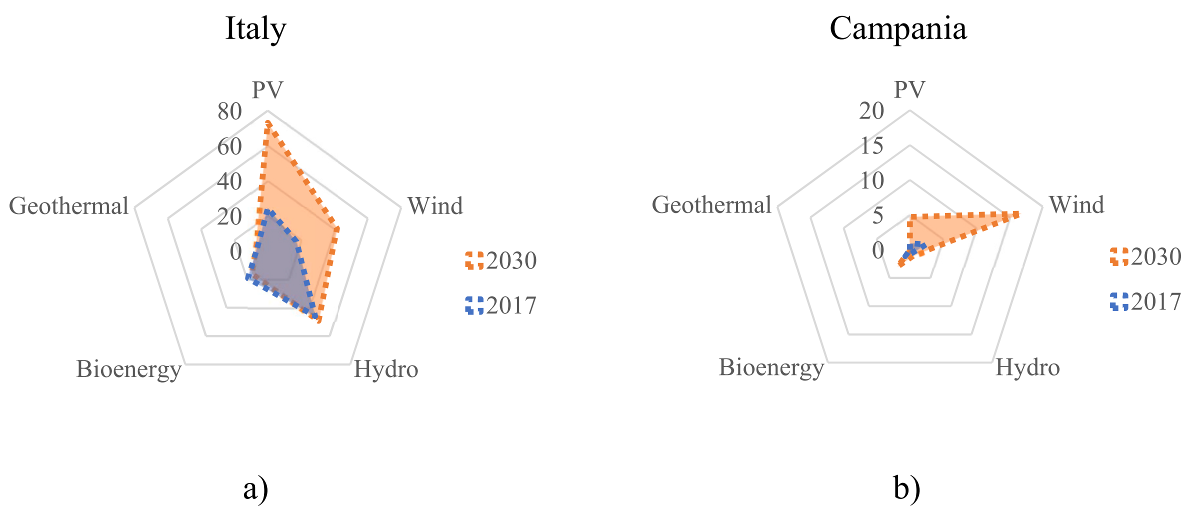


Fig. 15. Electric energy production (TWhe) by Hydro, Wind and Photovoltaic in 2017 and in 2030 for Italy (a) and Campania Region (b).

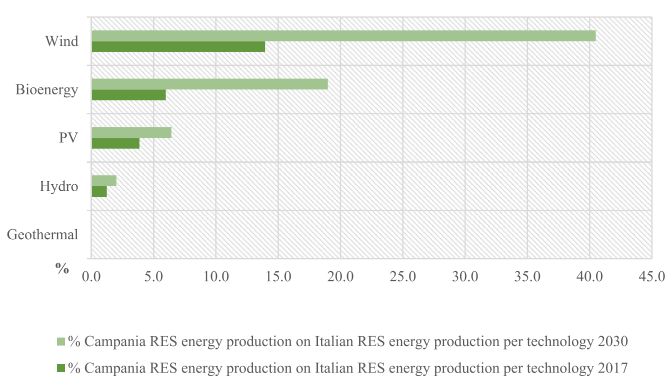
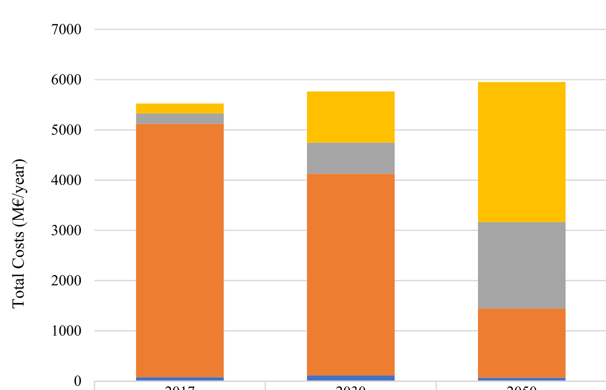


Fig. 16. Campania RES energy production on Italian RES energy production per Technology.

with:

- Investment
- Fuel
- $Fixed_{O\&M}$
- CO_2

In Fig. 17, the total costs associated with each scenario are shown. In addition to the investment, operating, and maintenance costs, the CO_2 and fuel costs are included. One notices that investment and fuel costs are the two main sources of expenditure in each scenario. As expected, the 2050 costs are much higher than those of 2030 and 2017. Almost 50% of the total cost are those related to investments in EVs (Table 3 in the Appendix). Estimation of the fuel costs involved considering the possible increases/decreases over the following 30-year period (see Table 6 in the Appendix). The related CO_2 emission costs are not proportionate to the gains associated with its reduction, because the price per kg/CO_2 used in the calculations was assumed to vary (see Table 5 in the Appendix). Fixed Operating and Maintenance costs were assumed to be a percentage of the investment costs, the latter of which were the reported literature values (see Table 4 in the Appendix).



	2017	2030	2050
Investment	197	1019.7	2789.2
Fixed O&M	208	617	1718.8
Fuel	5042	4018	1380
CO2 Emission costs	79	111	66

Fig. 17. Total energy costs for the 2017, 2030, and 2050 scenarios.

7. Conclusions

A future energy utilization strategy for Campania satisfying the European and Italian targets of reducing CO_2 emissions by 2030 and 2050 was developed.

Its energy mix was determined by considering the available resources and technologies with the aim of achieving an 80% reduction in the CO_2 emissions of Campania by 2050 compared to the 1990 levels.

For this reason, after identifying the energy consumption in the region for each sector and the potential sources of renewable energy present in the territory, the energy system was rebuilt within the 'EnergyPLAN' environment, where EnergyPLAN is a tool that allows one to implement and monitor the actions necessary to achieve the desired objectives.

Starting with the current energy system, the authors first determined a 2030 'transition' scenario for Campania, which involved an increase in the use of wind and solar energy for the 2030 and the installation of a district heating and cooling. After performing an energy analysis, the authors outlined an implementation strategy that would achieve a 40%–80% reduction in CO_2 emissions.

Using the 2030 scenario as a reference, the authors also outlined a 2050 scenario for Campania.

In the 2050 scenario: (1) up to 60% of the total thermal and cooling demands of the residential sector were satisfied by the district heating/cooling system; (ii) solar panels produced 0.5 TWh/year for individual heating, and photovoltaic panels produced 0.8 GW_e; (iii) new turbines provided up to 3.2 GW_e of wind energy.

The expansion of the RES technological capacity played a key role in the development of these energy systems. The flexibility of these energy systems was tested. It was found that configurations of this type often meet the energy security and environmental objectives but do not use all the energy produced by the RES technologies, increasing the amount of CEEP. A flexibility check consisted of evaluating the 'compromise' coefficient, namely COMP. The COMP for the 2030 scenario indicated that the energy system still possessed RES 'untapped potential'. The COMP for the 2050 scenario showed that the flexibility was optimal.

Moreover, the integration and coordination between different scales of energy planning was assessed. Authors evaluated the impacts of the Campania strategy on the National PNIEC forecasts for Italy 2030. Campania could contribute for reaching of the targets by increasing the quote of RES energy consumption from 5,5% to 5,9% of the national one and by reducing the quote of the final consumption from 5,8% to 5,1% of the national one.

Finally, an economic analysis of the three proposed scenarios allowed the authors to assess and compare the economic viability of the reference, 2030, and 2050 scenarios. The results indicated that the scenarios' total annual costs were similar (an approximate 7% increase from 2015 to 2050). However, the initial costs to implement the new technologies in the 2050 scenario remained very high, indicating that the process of financially transitioning from a 'traditional' energy system to a smart energy system (the primary component of which is the fleet of EVs) may need to be guided by a new legal framework and an incentive scheme.

Author statement

Salvatore Fabozzi: Conceptualization, Methodology, Validation, Software, Data curation, Writing – original draft, Visualization, **Giuseppina De Luca**: Conceptualization, Methodology, Validation, Software, Data curation Writing- Original draft preparation, Visualization, **Vittori Battaglia**: Methodology, Data curation Writing, Writing – original draft, Validation, Software, Visualization, **Laura Vanoli**: Conceptualization, Supervision, Reviewing and Editing, **Henrik Lund**: Supervision, Reviewing and Editing

Declaration of competing interest

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

Nomenclature

Acronyms and abbreviations

AD	Anaerobic Digestion
BAU	Business as Usual
CEEP	Critical Excess Electricity Production
C*EV*	Cost of Electric Vehicles
CHP	Combined Heat and Power
CO_2	Carbon dioxide
COMP	Compromise Coefficient
COP	Coefficient of Performance
CSP	Concentrated Solar Power
DHC	District Heating and Cooling
DHW	Domestic Hot Water
ESM	Energy System Management
EVs	Electric Vehicles
GHG	Greenhouse Gas
GIS	Geographic Information System
LCV	Lower Calorific Value
PV	Photovoltaic
PES	Primary Energy Supply
REEP	Regional Environmental Energy Plan
RES	Renewable Energy Sources
UAA	Utilized Agricultural Area

Subscript

e	Electric
o&m	Operation and Maintenance
th	Thermal
k	k-th plant

Appendix

1. Campania Energy System

Table 1
Number and capacity of the conventional thermal and electric RES plants in the Campania Region in 2017 [31,35,84].

Electricity		
	Number of Plants (n°)	Electric Power (MW_e)
	2017	2017
Thermal power plant	145	2.48×10^2
Photovoltaic	30 401	7.83×10^2
Wind	593	1.39×10^3
Hydro	59	3.42×10^2
Waste	1	1.20×10^2
Bioenergy	94	1.47×10^2

Table 2
Characteristics of the Heating and Cooling RES plants in the Campania Region [35].

Heating				
	Number of Plants	Thermal Capacity (MW_t)	Electric Capacity (MW_e)	Surface (m^2)
Biomass	12 510	2.50×10^2	–	–
Heat Pumps	3028	5.31×10^2	7.81×10^1	–
Thermal solar Panel	5883	–	–	4.91×10^4

2. Hourly distribution curves

Electric energy production by reference wind plants

The hourly energy production by wind turbines was obtained by monitoring a plant installed in the Campania Region. Fig. 1 shows the Campania hourly wind distribution curve for all the plants installed across the region.

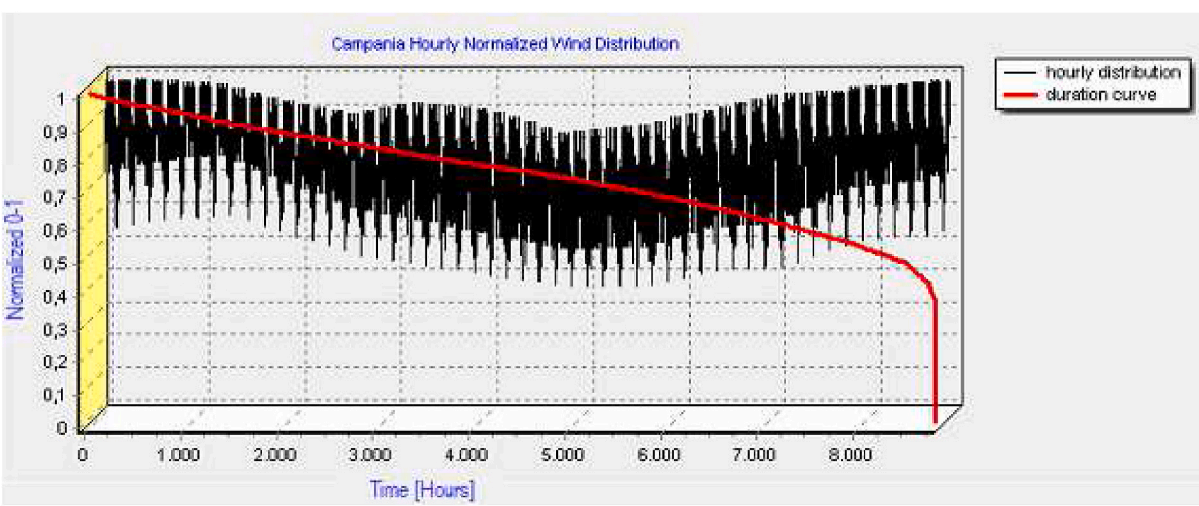


Fig. 1. Hourly wind distribution in Campania.

Electric energy production distribution by hydropower of reference model

The hourly hydro energy production data are obtain from TERNA database for South Italy [31]. In TERNA database, the hydroelectric plants are divided, according to the capacity of the reservoir, into three categories: reservoir plants, basin plants and run-of-river plants.

The corresponding hourly trend is shown in Fig. 2.

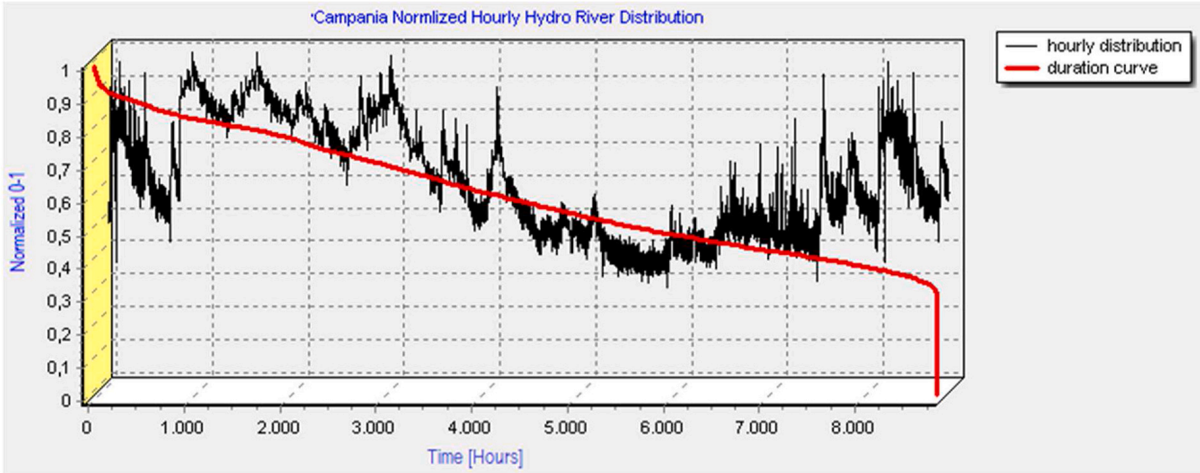


Fig. 2. Campania hourly Hydro River distribution.

Transportation hourly curve demand of reference model

The methodology proposed in Ref. [11] to build a distribution curve is used. It takes into account the measurement of air pollutants related to mobility. In fact, many pollutants present in the air are a direct consequence of the emissions produced by urban traffic; carbon monoxide, nitrogen dioxide, benzene, polycyclic aromatic hydrocarbons, inhalable dust [85]. Among all the pollutants mentioned above, about 80% of the benzene emissions are linked to petrol combustion and therefore directly connected to vehicular traffic. This assumption and the data provided by ACI [86], made it possible to achieve a transportation curve demand (Fig. 3) for the case studies analysed.

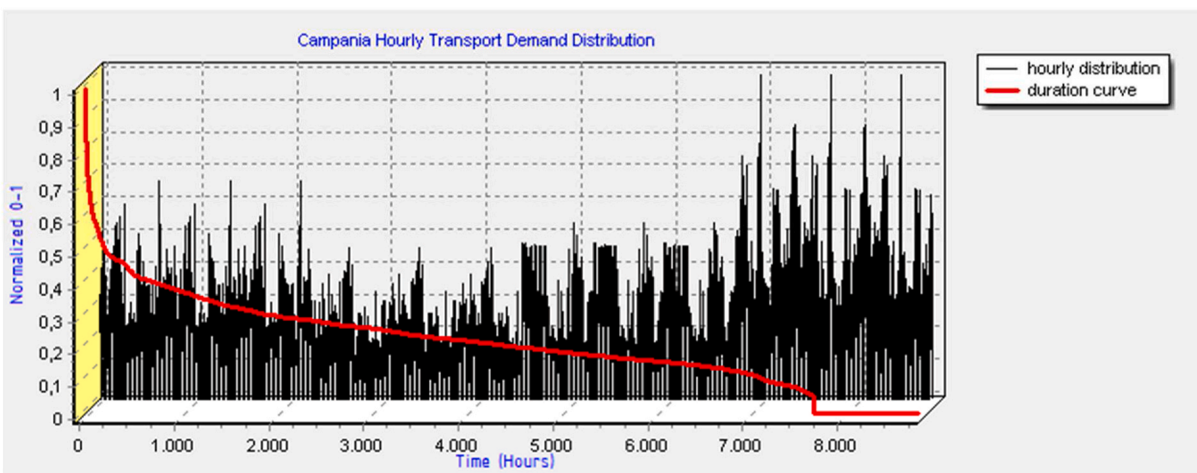


Fig. 3. Transport curve demand

3. *Cost Data*

Table 3

Technology costs and lifespan for scenarios 2017, 2030, and 2050 [87–94].

Sector	Technology	Units	Investment (M€/year)			Fixed O&M((M€/year)		
			2017	2030	2050	2017	2030	2050
HEAT AND ELECTRICITY	*Small CHP Units*	MWe	0	219	55	18	136	10
	Power Plant 1	MWe	0	39	20	18	16	8
	Heat Storage CHP	GWh	–	–	0	–	–	0
	Waste CHP	TWh/year	0	23	51		0	0
	Heat Pumps gr.2	MWe	–	75	71	–	4	4
	Heat Pumps gr.3	MWe		87			5	
	Individual CHP Electricity	TWh/year	0	4	3	2	2	1
	Individual CHP Heat	TWh/year	0	4	4	2	2	2
RENEWABLE ENERGY	*Wind Onshore*	MWe	0	85	241	38	54	161
	PV	MWe	0	26	39	7	8	12
	River Hydro	MWe	0	72	73	29	30	30

(continued on next page)

Table 3 (*continued*)

Sector	Technology	Units	Investment (M€/year)			Fixed O&M((M€/year)		
			2017	2030	2050	2017	2030	2050
	Geothermal	TWh/year	–	–	14	–	–	0
	Solar Thermal	TWh/year	–	3	3	–	0	0
	Heat Storage Solar	GWh	–	–	0	–	–	0
GAS FUELS	*Biogas Plant*	TWh/year	–	–	40	–	–	83
	Biogas Upgrade	MW	–	–	9	–	–	3
HEAT INFRASTRUCTURE	*Individual Heat Pumps*	1000 Units	–	–	32	–	–	3
ROAD VEHICLES	*N-gas Boilers*	1000 Units	197	98		94	97	
	Individual Solar Thermal	TWh/year	0	1	3	0	0	1
	Electric Cars	1000 Vehicles		43.2	2065.2		236	1400.2
Additional costs (CHP Plant)	*DH/DC*	TJ		157			40	
	EV Charging Station	–		83.5	66			20

Table 4
Average temperature and well depth of geothermal resources in Campania region [62].

Region area	Resource	Temperature (°C)	Well depth (m)
Campi Flegrei	Medium-high enthalpy	70–140	20–2,000
South-Est	Low enthalpy	60–90	1,500–2,500

Table 5
Lifetime and percentage of Fixed O&M costs for the technology of the 2017, 2030, and 2050 scenarios [87–94].

Sector	Technology	Units	Lifetime (years)			Fixed O&M (% of inv.)		
			2017	2030	2050	2017	2030	2050
Heat and electricity	*Small CHP units*	MWe	25	25	25	1	3.565	1
	Power Plant 1	MWe	25	25	32,5	2.31	2.32	2
	Heat Storage CHP	GWh	–	–	20	–	–	0.7
	Waste CHP	TWh/year	20	20	20	0	0	
	Heat Pumps gr.2	MWe	–	25	25	–	0.34	0.3
	Heat Pumps gr.3	MWe		25			0.3	
	Individual CHP electricity	TWh/year	31	31	31	2.14	2.14	2.15
	Individual CHP heat	TWh/year	31	31	31	2.14	2.14	2.15
Renewable energy	*Wind Onshore*	MWe	25	30	30	3.21	3.27	3.4
	PV	MWe	30	40	40	0.88	1.28	1,32
	River Hydro	MWe	60	60	60	1.5	1.5	1.5
	Geothermal Heat	TWh/year	–	25	30	–	2.45	0
	Solar Thermal	TWh/year	–	30	30	–	0.15	0.15
	Heat Storage Solar	GWh	–	–	20	–	–	0.7
Gas fuels	*Biogas Plant*	TWh/year	–	–	20	–	–	14
	Biogas Upgrade	MW	–	–	15	–	–	2.5
Heat infrastructure	*Individual Heat Pumps*	1000 Units	–	–	20	–	–	0.525
	Ngas Boilers	1000 Units	25	20		2.73	6.63	
	Individual Solar Thermal	TWh/year	25	30	30	1.22	1.35	1.68
Road vehicles	*Electric Cars*	1000 Vehicles	–	16	16	–	4.34	4.34
Additional cost	*DH/DC Infrastructures*	TJ		40	40	–	–	–
	Road Infrastructures				20	–	–	–

Table 6
Fuel costs by 2017, 2030, and 2050 [95,96].

Fuel	Oil			Diesel			Petrol			Ngas			Biomass		
Year	2017	2030	2050	2017	2030	2050	2017	2030	2050	2017	2030	2050	2017	2030	2050
Fuel Price (€/GJ)	17	17	17	20.9	20.9	2.,8	20.8	20.8	25.8	10.4	10.4	12.3	7.3	7.3	8

Table 7
CO_2 costs by 2017, 2030, and 2050 [87].

Scenario	2017	2030	2050
CO_2 Price (€/t)	5	11	16

References

[1] P. Fragkos, N. Tasios, L. Paroussos, P. Capros, S. Tsani, Energy System Impacts and Policy Implications of the European Intended Nationally Determined Contribution and Low-Carbon Pathway to 2050, Energy Policy, 2017, https://doi.org/10.1016/j.enpol.2016.10.023.
[2] P. Capros, et al., Outlook of the EU energy system up to 2050: the case of scenarios prepared for European Commission's 'clean energy for all Europeans' package using the PRIMES model, Energy Strategy Rev. (2018), https://doi.org/10.1016/j.esr.2018.06.009.
[3] J. Peter, How does climate change affect electricity system planning and optimal allocation of variable renewable energy? Appl. Energy (2019) https://doi.org/10.1016/j.apenergy.2019.113397.
[4] F. Calise, S. Di Fraia, A. Macaluso, N. Massarotti, L. Vanoli, A Geothermal Energy System for Wastewater Sludge Drying and Electricity Production in a Small Island, Energy, 2018, https://doi.org/10.1016/j.energy.2018.08.062.
[5] G. Krajačić, N. Duić, Z. Zmijarević, B.V. Mathiesen, A.A. Vučinić, M. Da Graa Carvalho, Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO2 emissions reduction, Appl. Therm. Eng. (2011), https://doi.org/10.1016/j.applthermaleng.2011.03.014.
[6] H. Lund, B.V. Mathiesen, Energy System Analysis of 100% Renewable Energy Systems-The Case of Denmark in Years 2030 and 2050, Energy, 2009, https://doi.org/10.1016/j.energy.2008.04.003.
[7] S. Di Fraia, S. Fabozzi, A. Macaluso, L. Vanoli, Energy potential of residual biomass from agro-industry in a Mediterranean region of southern Italy (Campania), J. Clean. Prod. 277 (2020) 124085, https://doi.org/10.1016/j.jclepro.2020.124085.
[8] O. Pupo-Roncallo, J. Campillo, D. Ingham, K. Hughes, M. Pourkashanian, Large Scale Integration of Renewable Energy Sources (RES) in the Future Colombian Energy System, Energy, 2019, https://doi.org/10.1016/j.energy.2019.07.135.
[9] I.G. Jensen, L. Skovsgaard, The Impact of CO2-costs on Biogas Usage, Energy, 2017, https://doi.org/10.1016/j.energy.2017.06.019.
[10] A.D. Korberg, I.R. Skov, B.V. Mathiesen, The Role of Biogas and Biogas-Derived Fuels in a 100% Renewable Energy System in Denmark, Energy, 2020, https://doi.org/10.1016/j.energy.2020.117426.
[11] G. De Luca, S. Fabozzi, N. Massarotti, L. Vanoli, A renewable energy system for a nearly zero greenhouse city: case study of a small city in southern Italy, Energy 143 (2018) 347–362, https://doi.org/10.1016/j.energy.2017.07.004.
[12] A. Carotenuto, et al., Energy analysis of a small geothermal district heating system in Southern Italy, Int. J. Heat Technol. 34 (2) (2016), https://doi.org/10.18280/ijht.34S246.
[13] S. Mellino, M. Ripa, A. Zucaro, S. Ulgiati, An emergy-GIS approach to the evaluation of renewable resource flows: a case study of Campania Region, Italy, Ecol. Model. (2014), https://doi.org/10.1016/j.ecolmodel.2012.12.023.
[14] C. Román-Figueroa, M. Paneque, Ethics and biofuel production in Chile, J. Agric. Environ. Ethics (2015), https://doi.org/10.1007/s10806-015-9535-1.
[15] T. Gomiero, M.G. Paoletti, D. Pimentel, Biofuels: efficiency, ethics, and limits to human appropriation of ecosystem services, J. Agric. Environ. Ethics (2010), https://doi.org/10.1007/s10806-009-9218-x.
[16] J. Fargione, J. Hill, D. Tilman, S. Polasky, P. Hawthorne, Land clearing and the biofuel carbon debt, Science (80-.) (2008), https://doi.org/10.1126/science.1152747.
[17] S. Kim, B.E. Dale, Life Cycle Assessment of Various Cropping Systems Utilized for Producing Biofuels: Bioethanol and Biodiesel, Biomass and Bioenergy, 2005, https://doi.org/10.1016/j.biombioe.2005.06.004.
[18] J. Hill, E. Nelson, D. Tilman, S. Polasky, D. Tiffany, Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels, Proc. Natl. Acad. Sci. U.S.A. (2006), https://doi.org/10.1073/pnas.0604600103.
[19] C. Liu, J. Wang, X. Ji, H. Qian, L. Huang, X. Lu, The biomethane producing potential in China: a theoretical and practical estimation, Chin. J. Chem. Eng. (2016), https://doi.org/10.1016/j.cjche.2015.12.025.
[20] A. Schievano, G. D'Imporzano, F. Adani, Substituting energy crops with organic wastes and agro-industrial residues for biogas production, J. Environ. Manag. 90 (8) (2009) 2537–2541, https://doi.org/10.1016/j.jenvman.2009.01.013.
[21] P.A. Østergaard, Reviewing optimisation criteria for energy systems analyses of renewable energy integration, Energy 34 (9) (2009) 1236–1245, https://doi.org/10.1016/j.energy.2009.05.004.
[22] A. Bonati, G. De Luca, S. Fabozzi, N. Massarotti, L. Vanoli, The integration of exergy criterion in energy planning analysis for 100% renewable system, Energy 174 (2019) 749–767, https://doi.org/10.1016/j.energy.2019.02.089.
[23] H. Lund, N. Duić, G. Krajačić, M. da Graça Carvalho, Two Energy System Analysis Models: A Comparison of Methodologies and Results, Energy, 2007, https://doi.org/10.1016/j.energy.2006.10.014.
[24] EnergyPLAN | Advanced energy systems analysis computer model. https://www.energyplan.eu/.
[25] IEA-ETSAP | Times. https://iea-etsap.org/index.php/etsap-tools/model-generators/times.
[26] References - software solutions for renewable EnergyEMD international. https://www.emd-international.com/energypro/references/.
[27] D. Henning, MODEST—an energy-system optimisation model applicable to local utilities and countries, Energy 22 (12) (1997) 1135–1150, https://doi.org/10.1016/S0360-5442(97)00052-2.
[28] Primes – E3 modelling [Online]. Available: https://e3modelling.com/modelling-tools/primes/.
[29] D. Connolly, H. Lund, B.V. Mathiesen, M. Leahy, A review of computer tools for analysing the integration of renewable energy into various energy systems, Appl. Energy (2010), https://doi.org/10.1016/j.apenergy.2009.09.026.
[30] S. Ferrari, F. Zagarella, P. Caputo, M. Bonomolo, Assessment of tools for urban energy planning, Energy 176 (2019) 544–551, https://doi.org/10.1016/j.energy.2019.04.054.
[31] Statistical publications - Terna spa. https://www.terna.it/it/sistema-elettrico.
[32] S.A. Klein, TRNSYS 17: A Transient System Simulation Program, Sol. Energy Lab. Univ. Wisconsin, Madison, USA, 2010.
[33] DesignBuilder. https://designbuilder.co.uk/35-designbuilder-software.
[34] Istat. https://www.istat.it/en/.
[35] GSE, Atlaimpianti. https://www.gse.it/dati-e-scenari/atlaimpianti.
[36] TERNA, Statistiche regionali 2019 [Online]. Available: https://www.terna.it/it/sistema-elettrico, 2020.
[37] APAT Agenzia per la protezione dell'ambiente e per i servizi tecnici [Online]. Available: https://www.isprambiente.gov.it/it/sistema-nazionale-protezione-ambiente.
[38] Database - eurostat. https://ec.europa.eu/eurostat/data/database.
[39] Integrated national energy and climate plan. https://www.mise.gov.it/index.php/it/notizie-stampa/2040668-pniec2030.
[40] P. Das, J. Mathur, R. Bhakar, A. Kanudia, Implications of short-term renewable energy resource intermittency in long-term power system planning, Energy Strategy Rev. (2018), https://doi.org/10.1016/j.esr.2018.06.005.
[41] A.S. Gaur, P. Das, A. Jain, R. Bhakar, J. Mathur, Long-term energy system planning considering short-term operational constraints, Energy Strategy Rev. (2019), https://doi.org/10.1016/j.esr.2019.100383.
[42] Tuttitalia.it - Guida ai Comuni, alle Province e alle Regioni d'Italia." .
[43] Decree of the president of the republic of Italy of 26 august 1993, n. 412 | build up. https://www.gazzettaufficiale.it/eli/id/1993/10/14/093G0451/sg.
[44] Piano Energetico Ambientale Regionale (PEAR) - energia da fonti rinnovabili - regione Campania. http://www.regione.campania.it/.
[45] H. Lund, W. Kempton, Analysis: large-scale integration of renewable energy, in: Renewable Energy Systems: A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions, second ed., 2014.
[46] L. Fernandes, P. Ferreira, Renewable Energy Scenarios in the Portuguese Electricity System, Energy, 2014, https://doi.org/10.1016/j.energy.2014.02.098.
[47] Heat roadmap Europe 3/stratego (2015) – heat roadmap Europe [Online]. Available: https://heatroadmap.eu/sp_faq/heat-roadmap-europe-3-stratego-2015/.
[48] Dati esercizio - Terna spa. https://www.terna.it/it/sistema-elettrico.
[49] Ministry of economic development - energy and mining analysis and statistics. https://dgsaie.mise.gov.it/prezzi-mensili-carburanti.
[50] Gme - gestore dei Mercati Energetici SpA. https://www.mercatoelettrico.org/It/Tools/Accessodati.aspx?ReturnUrl=%2FIt%2Fdownload%2FDownloadDati.aspx%3Fval%3DMGP_StimeFabbisogno&val=MGP_StimeFabbisogno.
[51] Meteonorm. https://meteonorm.com/en/.
[52] Istat.it population and households. https://www.istat.it/it/archivio/203344.
[53] F. Kreith, S.A. Sherif, D.Y. Goswami, E.K. Stefanakos, A. Steinfeld, Heating and cooling of buildings : principles and practice of energy efficient design, Heat. Cool. Build. (2016), https://doi.org/10.1201/9781315374567.
[54] Mathematical reference. http://www.trnsys.com/, 2006.
[55] W. De Soto, S.A. Klein, W.A. Beckman, Improvement and validation of a model for photovoltaic array performance, Sol. Energy (2006), https://doi.org/10.1016/j.solener.2005.06.010.
[56] I. Bačeković, P.A. Østergaard, Local Smart Energy Systems and Cross-System Integration, Energy, 2018, https://doi.org/10.1016/j.energy.2018.03.098.
[57] Previsioni della domanda elettrica - Terna spa. https://www.terna.it/it/sistema-elettrico.
[58] Analisi e risultati delle policy di efficienza energetica del nostro paese agenzia nazionale efficienza energetica. https://www.enea.it/it/seguici/pubblicazioni/pdf-volumi/2020/raee-2020.pdf.
[59] H.S. Das, M.M. Rahman, S. Li, C.W. Tan, Electric vehicles standards, charging infrastructure, and impact on grid integration: a technological review, Renew. Sustain. Energy Rev. (2020), https://doi.org/10.1016/j.rser.2019.109618.
[60] E-mobility revolution. Gli impatti sulle filiere industriali e sul sistema-paese: quale agenda per l'italia. https://www.enel.com/it/media/esplora/ricerca-comunicati

-stampa/press/2017/09/e-mobility-revolution-gli-impatti-sulle-filiere-industriali-e-sul-sistema-paese-quale-agenda-per-litalia.
[61] Studi e pubblicazioni - anev. https://www.anev.org/.
[62] Home di VIGOR. http://www.vigor-geotermia.it/.
[63] S. Carlino, Heat flow and geothermal gradients of the Campania region (Southern Italy) and their relationship to volcanism and tectonics, J. Volcanol. Geoth. Res. (2018), https://doi.org/10.1016/j.jvolgeores.2018.10.015.
[64] N.N. Novitsky, A.V. Alekseev, O.A. Grebneva, A.V. Lutsenko, V.V. Tokarev, Z. I. Shalaginova, Multilevel Modeling and Optimization of Large-Scale Pipeline Systems Operation, Energy, 2019, https://doi.org/10.1016/j.energy.2018.02.070.
[65] EN ISO 52003-1 Energy Performance of Buildings – Indicators, Requirements, Ratings and Certificates– Part 1: General Aspects.".
[66] ISPRA, Scenari di consumi elettrici al 2050, Rome [Online]. Available: http://www.isprambiente.gov.it, 2015.
[67] BioBoost project. https://www.bioboost.eu/.
[68] S.p.A. Terna Rete Italia, Scenario national trend italia [Online]. Available: https://www.terna.it/en/electric-system/grid/national-electricity-transmission-grid-development-plan/scenarios, 2021.
[69] C. Biogas, Lo sviluppo del biometano e la strategia di decarbonizzazione in Italia [Online]. Available: https://www.consorziobiogas.it/wp-content/uploads/2016/12/Position-Paper-CIB-Snam-confagri-ita.pdf.
[70] S. Pindozzi, S. Faugno, E. Cervelli, A. Capolupo, M. Sannino, L. Boccia, Consequence of land use changes into energy crops in Campania region, J. Agric. Eng. (s1) (2013) e93, https://doi.org/10.4081/jae.2013.
[71] L.R. Lynd, M.S. Laser, J. McBride, K. Podkaminer, J. Hannon, Energy myth three-high land requirements and an unfavorable energy balance preclude biomass ethanol from playing a large role in providing energy services, in: Energy and American Society - Thirteen Myths, 2007.
[72] Consorzio Italiano Compostatori, CIC dati annuali sintetici [Online]. Available: https://www.compost.it/en/.
[73] Regione Campania, Disciplina tecnica per la utilizzazione dei liquami zootecnici [Online]. Available: https://www.regione.campania.it/.
[74] P.A. Østergaard, Reviewing EnergyPLAN simulations and performance indicator applications in EnergyPLAN simulations, Appl. Energy 154 (2015) 921–933, https://doi.org/10.1016/j.apenergy.2015.05.086.
[75] M.B. Blarke, H. Lund, The effectiveness of storage and relocation options in renewable energy systems, Renew. Energy 33 (7) (2008) 1499–1507, https://doi.org/10.1016/j.renene.2007.09.001.
[76] P. Nunes, T. Farias, M.C. Brito, Day charging electric vehicles with excess solar electricity for a sustainable energy system, Energy 80 (2015) 263–274, https://doi.org/10.1016/j.energy.2014.11.069.
[77] P. Denholm, R.M. Margolis, Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems, Energy Pol. 35 (5) (2007) 2852–2861, https://doi.org/10.1016/j.enpol.2006.10.014.
[78] D. Connolly, H. Lund, B.V. Mathiesen, M. Leahy, The first step towards a 100% renewable energy-system for Ireland, Appl. Energy (2011), https://doi.org/10.1016/j.apenergy.2010.03.006.
[79] W. Liu, H. Lund, B.V. Mathiesen, Large-scale integration of wind power into the existing Chinese energy system, Energy 36 (8) (2011) 4753–4760, https://doi.org/10.1016/j.energy.2011.05.007.
[80] D. Connolly, H. Lund, B.V. Mathiesen, E. Pican, M. Leahy, The technical and economic implications of integrating fluctuating renewable energy using energy storage, Renew. Energy 43 (2012) 47–60, https://doi.org/10.1016/j.renene.2011.11.003.
[81] B. Ćosić, G. Krajačić, N. Duić, A 100% renewable energy system in the year 2050: the case of Macedonia, Energy 48 (1) (2012) 80–87, https://doi.org/10.1016/j.energy.2012.06.078.
[82] K. Hedegaard, B.V. Mathiesen, H. Lund, P. Heiselberg, Wind power integration using individual heat pumps - analysis of different heat storage options, Energy 47 (1) (2012) 284–293, https://doi.org/10.1016/j.energy.2012.09.030.
[83] G. Azzone, P. Secchi, D. Zaninelli, Apriamo La strada Al trasporto elettrico nazionale. https://www.enelfoundation.org/all-news/news/2018/11/round-table-in-aspen-institute-italia-on-sustainable-mobility.
[84] Trasmettiamo energia. https://www.t2i.it/events/event/trasmettiamo-energia/.
[85] Air pollutant emissions — EEA datasets — European Environment Agency. https://www.eea.europa.eu/data-and-maps/data#c0=5&c11=&c5=all&b_start=0.
[86] Servizi ACI. https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche.html.
[87] Technology data for individual heating plants | energistyrelsen. https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-individual-heating-plants.
[88] Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables) | Energy. https://ec.europa.eu/energy/studies_main/final_studiesmapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel_en.
[89] Hourly labour costs ranged from €5.4 to €43.5 across the EU Member States in 2018 [Online]. Available: https://ec.europa.eu/eurostat/documents/2995521/9720156/3-11042019-BP-EN/3240675b-5513-41a4-8b28-3f5e24c55b70, 2019.
[90] Projected costs of generating electricity 2020 – analysis - IEA. https://www.iea.org/.
[91] Renewable power generation costs in 2019. https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019.
[92] Electricity Storage and Renewables: Costs and Markets to 2030,"/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets.
[93] The IEA SHC programme – PlanEnergi. https://www.iea.org/.
[94] Cost database | EnergyPLAN. https://www.energyplan.eu/.
[95] B.V. Mathiesen, et al., IDA's Energy Vision 2050, A Smart Energy System strategy for 100% renewable Denmark, 2015.
[96] Energistyrelsen, Samfundsøkonomiske Beregningsforudsætninger, Forside » Info » Tal og kort » Fremskrivninger, analyser og modeller, 2015.
[97] A sustainable mobility strategy based on electric vehicles and photovoltaic panels for shopping centers, Sustain. Cities Soc. 70 (2021), https://doi.org/10.1016/j.scs.2021.102891.