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# Energy Planning of Renewable Energy Sources in an Italian Context: Energy Forecasting Analysis of Photovoltaic Systems in the Residential Sector

**Domenico Palladino * and Nicolandrea Calabrese**

DUEE Department, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Via Anguillarese 301, Santa Maria di Galeria, 00123 Rome, Italy
* Correspondence: domenico.palladino@enea.it

**Abstract:** Solar photovoltaic systems will play a key role in the country's energy mix thanks to their ability to meet increasing energy needs while reducing greenhouse gas emissions. Despite the potential of solar photovoltaic energy, several criticalities remain, such as the intermittent nature and the need for significant land use for its implementation. In this regard, this work aimed at evaluating the photovoltaic potentiality in a national context by 2030 and 2050, considering only installations on the roof surfaces of existing buildings, i.e., without consuming additional land. This study has allowed the answering of three key points: (i) the roof surface could represent a valuable and alternative solution for new installations, since it could amount to around 450 $km^2$, (ii) the national target cannot be reached by only using installations on existing buildings, although some regions could get close to the target by 2050, and (iii) long-term energy incentives should be implemented branching out to each national region, considering their photovoltaic potential. Finally, a regional potential index was also defined, capable of evaluating the photovoltaic potential in each region, helping policymakers to adopt the most suitable energy strategies.

**Keywords:** photovoltaic energy system; energy supply security; energy planning; renewable energy source; domestic energy consumption; photovoltaic potentiality



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## 1. Introduction

The current geopolitical situation has highlighted multiple issues in the energy strategies of many countries looking for alternative energy sources to fossil fuels. In addition, the new European targets of achieving net-zero emissions by 2050 and the decoupling of national growth from the use of resources have led to a breakthrough in the green transition of the European Union to reduce net emissions by 2030 compared to 1990 levels [1]. Among the actions undertaken to achieve these objectives is the promotion of the use of renewable energy sources and the energy efficiency of buildings, which remains one of the main sectors accountable for total energy consumption.

In Italy, residential buildings are still accountable for 12% of total emissions [2], corresponding to about 30% of total energy requirements [3], mainly due to heating energy services, and mostly due to poor building envelope performance. In recent years, multiple energy efficiency actions have been implemented, ranging from the renovation of the whole national building stock, such as the Superbonus scheme [4], to raising awareness of the use of high-energy class equipment. However, this sector, which includes more than 12 million buildings across the country [5], is one of the most energy-intensive sectors, with an electricity consumption of over 65,500 GWh on average in the last years [6–13]. Among the possible strategies to cover this energy need could be the massive use of photovoltaic systems, since over 1100 kWh per kW of installed power could be produced on average across the country [14–19].

Solar photovoltaic energy could be crucial both in Europe and Italy due to its potential of meeting increasing energy needs while reducing greenhouse gas emissions. According to a study carried out by the International Energy Agency (IEA), Italy set an ambitious target of 52 GW of photovoltaic capacity by 2030, i.e., around 2.5 times the value recorded in 2020, indicating photovoltaic systems as a key player in the country's energy mix [20].

In the literature, photovoltaics is widely studied, both in terms of technology development and forecasting model implementation. Only in the last year, a large number of studies were carried out with different purposes, such as performing energy and exergy balances of photovoltaic systems [21–25], the analysis of new materials or photovoltaic technologies [26,27], forecasting analysis to check its potentiality over the years [28–31] by also using machine learning [32–34] or other specific methods [35–37], or to analyze national energy policy [38,39].

Despite the potential and convenience of solar photovoltaic energy, as highlighted in these works, there are several criticalities: the intermittent nature of solar energy, the need for significant land use for its implementation, high levels of bureaucracy, and the regulatory uncertainties that have hindered the growth of the sector. As an energy policy, solar photovoltaic energy could have significant potential to become one of the major sources of electricity. Nevertheless, there are relevant challenges that need to be addressed, particularly concerning land use.

To increase the number of photovoltaic installations, Italy has issued the new Law Decree n. 17 of 2022 [40] aiming at reducing the levels of bureaucracy and promoting new installations of photovoltaic systems on the roofs of existing buildings, including those falling in A-zones, i.e., the historical city centers.

As a result of this framework, this study aimed at evaluating the potentiality and energy production of photovoltaics in a national context. In particular, as photovoltaic systems will play a key role in the national energy mix, this study was performed to understand the real potential of photovoltaics by 2030–2050 when only installed on the roofs of existing buildings, i.e., without consuming additional land. The study aims to answer three key points in detail:

(1) Is it possible to use only the roof surface of existing buildings for the new installations of photovoltaic panels?
(2) What could be the productivity of the photovoltaic panels by 2050 and what could be the theoretical maximum power that could be placed on the roof surface of existing buildings?
(3) Would it be possible to meet European targets by placing photovoltaic panels only on the roof surfaces of existing buildings?

To answer these key questions, a careful research procedure was adopted aimed at (i) evaluating the roof surface available for new installations of photovoltaic systems, (ii) understanding the current number of installations and productivity of the photovoltaic systems placed only in the residential sector, (iii) assessing the growth rates of photovoltaic panels in the residential sector, (iv) performing a forecast analysis, and (v) analyzing and comparing the theoretical photovoltaic energy production with respect to European targets.

The paper is structured as follows: the research procedure is detailed in Section 2, the underlying current energy consumption of the residential sector (Section 2.1), the state-of-the-art photovoltaic system (Section 2.2), and the theoretical roof surface of existing buildings (Section 2.3). As national reports provide disaggregated data only on an annual basis, a comparison of the energy production of photovoltaic panels on a monthly and annual basis was also performed to check the reliability of the annual forecasting analysis. This discussion is reported at the beginning of Section 3 (Section 3.1). Finally, the results of the forecasting analysis were discussed in Section 3.2, whilst the main findings are remarked upon in the conclusions.

## 2. Materials and Methods

The forecasting analysis was performed by planning a detailed research procedure (Figure 1) based on: (i) the energy consumption of the buildings sector, based on national reports provided by the National Electricity Network [6–13], (ii) the state-of-the-art photovoltaic panels placed only on the roofs of residential buildings, according to the annual reports provided by Energy Services Manager [14–19], and (iii) the type and number of building units as well as their roof surface area across the country, assessed from data provided by the National Institute of Statistics [5]. Data from the National Electricity Network and Energy Services Manager is provided for each Italian region; therefore, all of the analyses were carried out in regional detail. However, for clarity in the presentation, the aggregated results are discussed, distinguishing five Italian zones:

- Northwest: including Valle d'Aosta, Piemonte, Liguria, and Lombardia regions;
- Northeast: including Trentino, Friuli Venezia Giulia, Veneto, and Emilia Romagna;
- Centre: grouping Toscana, Umbria, Marche, and Lazio;
- South: grouping Abruzzo, Campania, Molise, Puglia, Basilicata, and Calabria;
- Islands: including the two islands of Sicilia and Sardegna.

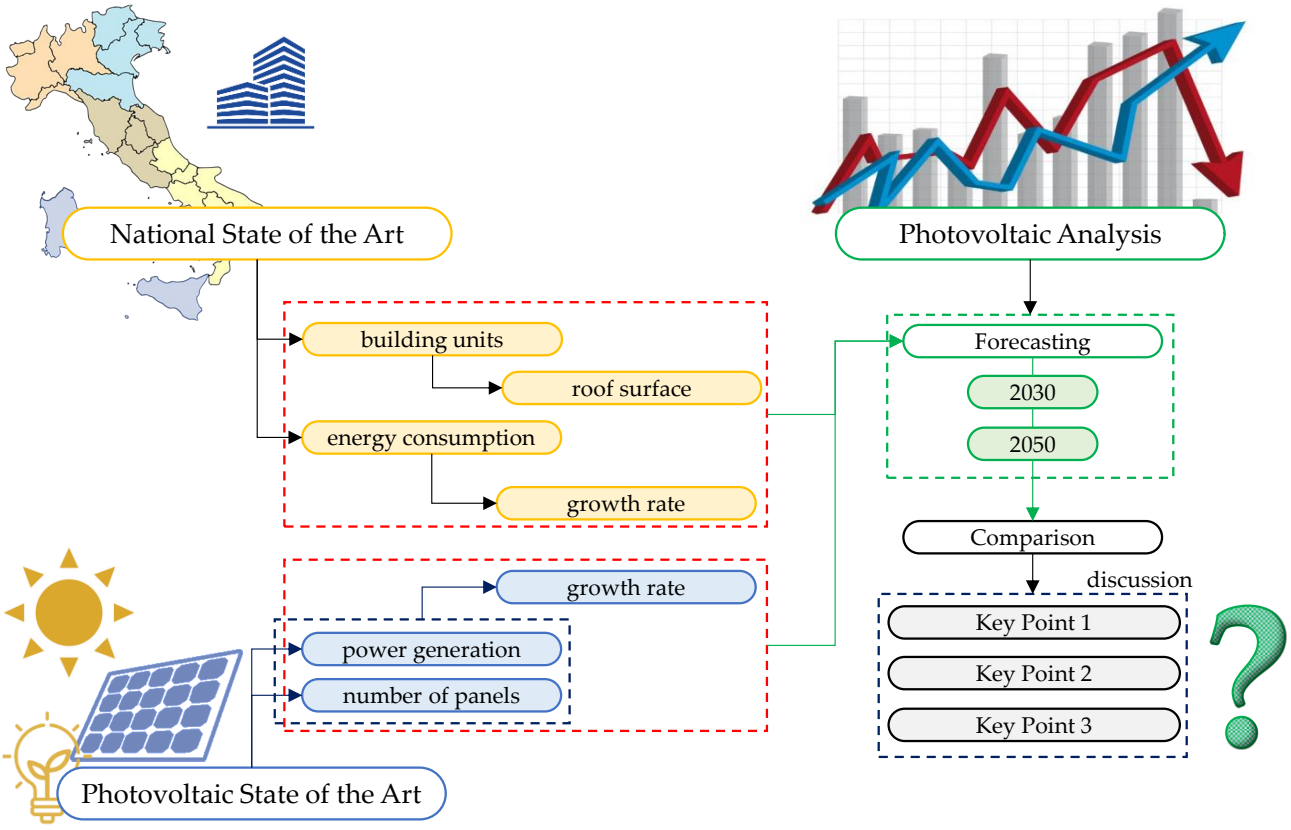


**Figure 1.** Research procedure adopted for performing photovoltaic forecasting.

A key point of the work consists of the evaluation of the available roof surface area where photovoltaic panels could be placed; in fact, one of the purposes of the study is to check the possibility of using existing surfaces for this kind of application, i.e., without further land use. For this analysis, an estimation of the roof surface area of existing buildings starting with data provided by the National Institute of Statistics [5] was attempted.

Furthermore, for each region, the growth rates relating to the number and peak power of photovoltaic panels placed on existing buildings and the energy consumption of the building sector were also estimated. In addition, the improvements in photovoltaic panels over the year could also be taken into account, although the developments of this technology in the future are neither available nor foreseeable. For that reason, the following growth or

development rates (GR or DR) were taken into account for the forecasting analysis based on data availability:

- Growth rate of energy consumption ($GR_{EC}$): this was calculated considering the annual growth rates from 2014 (see Section 2.1);
- Growth rate of photovoltaic panels ($GR_{PhV}$): this was calculated considering the annual growth rates from 2016 (see Section 2.2);
- Development rate of photovoltaic panels ($DR_{P\text{-}PhV}$): this was calculated considering the annual development rates recorded from 2016 (see Section 2.2).

The mean annual values of energy consumption and the number of new installations of photovoltaic panels were also calculated and assumed as the reference values (data used from 2022) for the forecasting analysis by applying different GR values.

Finally, the forecasting analysis was performed for 2050 by checking: (i) the photovoltaic power installed by 2030 and 2050, (ii) the theoretical roof area needed for photovoltaic panels, and (iii) the energy need covered by photovoltaic panels. The forecasting analysis was performed with and without $DR_{P\text{-}PhV}$ to highlight the increase in energy production due to technology development.

Results were finally analyzed to evaluate the achievement of the national targets by 2030 and 2050 and to underline the potentiality and the issues of only installing photovoltaic systems on the roofs of existing buildings.

### *2.1. Energy Consumption of National Buildings Stock*

The electrical energy consumption of the national building stock was assessed in agreement with national annual reports provided by the National Electricity Network [6–13]; in particular, the available data on an annual basis between 2014 and 2021 was taken into account (Table 1).

**Table 1.** Electrical energy consumption (GWh) for the residential building stock of each region and national zone: data from the National Electricity Network [6–13].

| National Zones | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|
| Valle d'Aosta | 178.4 | 175.9 | 176.6 | 176.6 | 177.9 | 165.7 | 161.0 | 156.2 |
| Piemonte | 4579.3 | 4627.1 | 4538.6 | 4554.3 | 4555.6 | 4545.3 | 4623.2 | 4534.8 |
| Liguria | 1729.9 | 1737.5 | 1701.0 | 1693.0 | 1698.8 | 1687.3 | 1699.5 | 1686.5 |
| Lombardia | 10,999.5 | 11,341.4 | 11,124.3 | 11,258.9 | 11,333.8 | 11,511.6 | 11,456.7 | 11,346.1 |
| Trentino Alto Adige | 1195.2 | 1149.2 | 1156.2 | 1148.6 | 1160.1 | 1164.0 | 1158.9 | 1160.9 |
| Veneto | 5195.5 | 5570.4 | 5396.5 | 5552.7 | 5595.5 | 5688.0 | 5644.3 | 5747.4 |
| Friuli Venezia Giulia | 1316.4 | 1369.4 | 1340.2 | 1381.4 | 1391.2 | 1383.0 | 1377.4 | 1397.1 |
| Emilia Romagna | 4900.0 | 5201.7 | 5041.2 | 5136.2 | 5143.5 | 5159.8 | 5174.8 | 5199.8 |
| Toscana | 4032.9 | 4110.5 | 4026.9 | 4082.1 | 4087.0 | 4126.3 | 4156.8 | 4146.2 |
| Umbria | 912.0 | 935.4 | 907.6 | 926.3 | 921.6 | 925.2 | 938.4 | 945.4 |
| Marche | 1520.0 | 1555.2 | 1513.2 | 1537.2 | 1546.4 | 1543.7 | 1567.3 | 1584.6 |
| Lazio | 6699.9 | 6852.9 | 6670.5 | 6686.3 | 6456.3 | 6322.4 | 6518 | 6551.6 |
| Abruzzo | 1286.4 | 1320.9 | 1286.6 | 1304.8 | 1294.2 | 1318.1 | 1317.7 | 1337.1 |
| Molise | 284.4 | 286.4 | 279.8 | 282.4 | 276.1 | 277.7 | 281.0 | 284.8 |
| Campania | 5351.9 | 5484.1 | 5260.1 | 5347.6 | 5312.1 | 5443.8 | 5532.3 | 5633.0 |
| Puglia | 3988.5 | 4160.7 | 3996.7 | 4168.6 | 4100.6 | 4133.9 | 4175.4 | 4397.9 |
| Basilicata | 490.3 | 498.9 | 488.5 | 503.2 | 494.0 | 495.6 | 501.1 | 512.0 |
| Calabria | 1998.1 | 2044.8 | 1984.2 | 2041.9 | 1992.2 | 2036.3 | 2036.2 | 2120.7 |
| Sicilia | 5481.8 | 5614.1 | 5340.6 | 5552 | 5436.9 | 5433.2 | 5666.2 | 5974.6 |
| Sardegna | 2114.5 | 2150.5 | 2074.7 | 2156.6 | 2164.0 | 2277.1 | 2225.7 | 2335.5 |
| Northwest | 17,487.1 | 17,881.9 | 17,540.5 | 17,682.8 | 17,766.1 | 17,909.9 | 17,940.4 | 17,723.6 |
| Northeast | 12,607.1 | 13,290.7 | 12,934.1 | 13,218.9 | 13,290.3 | 13,394.8 | 13,355.4 | 13,505.2 |
| Centre | 13,164.8 | 13,454 | 13,118.2 | 13,231.9 | 13,011.3 | 12,917.6 | 13,180.5 | 13,227.8 |
| South | 13,399.6 | 13,795.8 | 13,295.9 | 13,648.5 | 13,469.2 | 13,705.4 | 13,843.7 | 14,285.5 |
| Islands | 7596.3 | 7764.6 | 7415.3 | 7708.6 | 7600.9 | 7710.3 | 7891.9 | 8310.1 |
| Total | 64,254.9 | 66,187 | 64,304 | 65,490.7 | 65,137.8 | 65,638 | 66,211.9 | 67,052.2 |

According to this data, a slight but significant variation (in relative terms) in electricity consumption can be highlighted; in fact, the energy consumption of the building sector has varied over the years by a value between −6.86% (Valle d'Aosta, 2019) and +7.22% (Veneto, 2015). Based on this trend, annual growth rates associated with energy consumption ($GR_{EC}$) were estimated for each region as the relative difference between two consecutive years. Starting from these values, a mean $GR_{EC}$ was assessed and used to evaluate the variation in electrical energy consumption of the national building stock in the forecasting analysis. The mean $GR_{EC}$ assessed from the data in Table 1 is reported in the next section (see Section 3.2).

### *2.2. Photovoltaic Systems: Growth and Development Rates and Energy Production*

Based on the annual reports provided by Energy Services Manager [14–19], the state-of-the-art photovoltaic systems in the residential building sector were also detailed. In this case, disaggregated data were available only from 2016 and on an annual basis, although more information on photovoltaic systems is available from 2008. The number of photovoltaic panel installations on the roofs of the building stock and the total photovoltaic power produced every investigated year is detailed in Tables 2 and 3, whilst the roof surface required for photovoltaic panels is reported in Table 4. It is worth noting that while the number of new photovoltaic panel installations and the photovoltaic power output are both provided by national reports, the roof surface area required by photovoltaic panels was assessed considering an average area per kW of 6.18 $m^2$/kW. This average value was evaluated based on the surface generally required by polycrystalline panels (the most common solution as indicated in [14–19]) with nominal power of between 150 and 450 W, and increased by a precautionary factor of 1.25.

**Table 2.** The total number of photovoltaic installations installed each year (-): data provided by the Energy Services Manager [14–19].

| National Zones | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| Valle d'Aosta | 1610 | 1738 | 1833 | 1925 | 1972 | 2094 |
| Piemonte | 39,350 | 41,976 | 44,641 | 48,030 | 50,060 | 54,141 |
| Liguria | 6204 | 6677 | 7219 | 7811 | 8282 | 8792 |
| Lombardia | 87,343 | 94,721 | 102,340 | 111,356 | 119,000 | 131,822 |
| Trentino Alto Adige | 16,715 | 17,568 | 18,284 | 19,056 | 19,004 | 20,287 |
| Veneto | 83,891 | 90,150 | 97,453 | 106,419 | 113,993 | 126,203 |
| Friuli Venezia Giulia | 25,784 | 27,159 | 28,660 | 30,323 | 31,480 | 33,395 |
| Emilia Romagna | 59,075 | 63,572 | 68,189 | 73,724 | 77,773 | 84,471 |
| Toscana | 30,705 | 32,565 | 34,604 | 36,999 | 38,420 | 41,666 |
| Umbria | 13,238 | 13,971 | 14,929 | 15,829 | 16,466 | 16,077 |
| Marche | 18,887 | 20,263 | 21,315 | 22,731 | 23,607 | 24,924 |
| Lazio | 39,906 | 43,526 | 47,159 | 51,268 | 54,328 | 58,368 |
| Abruzzo | 13,240 | 15,200 | 16,118 | 17,205 | 17,437 | 18,005 |
| Molise | 2748 | 2948 | 3049 | 3214 | 3282 | 3367 |
| Campania | 22,514 | 24,110 | 25,816 | 27,817 | 28,781 | 31,077 |
| Puglia | 30,903 | 36,235 | 38,117 | 40,644 | 42,551 | 42,782 |
| Basilicata | 4959 | 5393 | 5612 | 5974 | 5994 | 6186 |
| Calabria | 17,367 | 18,546 | 19,509 | 20,676 | 21,255 | 22,539 |
| Sicilia | 37,111 | 41,123 | 43,634 | 46,727 | 48,888 | 50,930 |
| Sardegna | 28,435 | 30,248 | 31,643 | 33,384 | 34,226 | 35,484 |
| Northwest | 134,507 | 145,112 | 156,033 | 169,122 | 179,314 | 196,849 |
| Northeast | 185,465 | 198,449 | 212,586 | 229,522 | 242,250 | 264,356 |
| Centre | 102,736 | 110,325 | 118,007 | 126,827 | 132,821 | 141,035 |
| South | 91,731 | 102,432 | 108,221 | 115,530 | 119,300 | 123,956 |
| Islands | 65,546 | 71,371 | 75,277 | 80,111 | 83,114 | 86,414 |
| Total | 579,985 | 627,689 | 670,124 | 721,112 | 756,799 | 812,610 |

**Table 3.** Annual photovoltaic panel power output (MW): data provided by Energy Services Manager [14–19].

| National Zones | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| Valle d'Aosta | 8.0 | 9.0 | 9.0 | 10.0 | 9.0 | 10.0 |
| Piemonte | 198.0 | 209.0 | 220.0 | 235.0 | 232.0 | 253.0 |
| Liguria | 26.0 | 29.0 | 31.0 | 34.0 | 34.0 | 37.0 |
| Lombardia | 390.0 | 421.0 | 453.0 | 493.0 | 516.0 | 578.0 |
| Trentino Alto Adige | 80.0 | 90.0 | 94.0 | 97.0 | 88.0 | 92.0 |
| Veneto | 393.0 | 421.0 | 451.0 | 491.0 | 509.0 | 568.0 |
| Friuli Venezia Giulia | 126.0 | 129.0 | 135.0 | 143.0 | 145.0 | 155.0 |
| Emilia Romagna | 271.0 | 287.0 | 306.0 | 330.0 | 330.0 | 361.0 |
| Toscana | 139.0 | 148.0 | 156.0 | 166.0 | 166.0 | 182.0 |
| Umbria | 62.0 | 66.0 | 70.0 | 74.0 | 73.0 | 73.0 |
| Marche | 93.0 | 100.0 | 104.0 | 110.0 | 106.0 | 111.0 |
| Lazio | 183.0 | 199.0 | 213.0 | 230.0 | 239.0 | 257.0 |
| Abruzzo | 71.0 | 84.0 | 88.0 | 93.0 | 88.0 | 91.0 |
| Molise | 16.0 | 17.0 | 18.0 | 19.0 | 18.0 | 18.0 |
| Campania | 118.0 | 126.0 | 134.0 | 144.0 | 145.0 | 158.0 |
| Puglia | 159.0 | 188.0 | 196.0 | 207.0 | 206.0 | 206.0 |
| Basilicata | 29.0 | 31.0 | 32.0 | 33.0 | 31.0 | 32.0 |
| Calabria | 96.0 | 106.0 | 111.0 | 117.0 | 114.0 | 120.0 |
| Sicilia | 199.0 | 221.0 | 232.0 | 247.0 | 250.0 | 262.0 |
| Sardegna | 136.0 | 148.0 | 154.0 | 161.0 | 159.0 | 163.0 |
| Northwest | 622.0 | 668.0 | 713.0 | 772.0 | 791.0 | 878.0 |
| Northeast | 870.0 | 927.0 | 986.0 | 1061.0 | 1072.0 | 1176.0 |
| Centre | 477.0 | 513.0 | 543.0 | 580.0 | 584.0 | 623.0 |
| South | 489.0 | 552.0 | 579.0 | 613.0 | 602.0 | 625.0 |
| Islands | 335.0 | 369.0 | 386.0 | 408.0 | 409.0 | 425.0 |
| Total | 2793.0 | 3029.0 | 3207.0 | 3434.0 | 3458.0 | 3727.0 |

According to data from the national reports [14–19], it was worth noting that the highest number of installations can be found in the Northeast zone of Italy (around 15,780 photovoltaic installations overall) thanks to the highest number of new installations found in Lombardia in 2021. Although the Islands zone takes into account only two regions (Sardegna and Sicilia), it is worth noting that the number of installations is similar to the number for the South, as well as the photovoltaic power and roof surface area occupied by photovoltaic panels, highlighting the strong impact of this technology in these two regions.

Based on this data, some growth rates correlated to the number of new installations ($GR_{PhV}$) were assessed (Table 5); in particular, four growth rates for each region were considered:

- $GR_{PhV\text{-}1}$: this was assessed as the mean value considering all of the available data from 2016 to 2021;
- $GR_{PhV\text{-}2}$: this was assessed as the mean value considering all of the available data by excluding the extreme values (i.e., the minimum and the maximum values in order to neglect the effect of the last national incentive (Superbonus), which led to a significant increase in the number of new installations in many regions);
- $GR_{PhV\text{-}3}$: this was assessed as the maximum value considering all of the available data but excluding the extreme values;
- $GR_{PhV\text{-}4}$: this was assessed as the minimum value considering all of the available data but excluding the extreme values.

Furthermore, based on data assessed or provided by national reports, the mean values in terms of photovoltaic power, the number of installations, energy production, and roof surface area required for each installation were finally assessed and assumed as reference values from 2022 (see Section 3) as this information is not yet available.

**Table 4.** Theoretical total roof surface area required for photovoltaic panel installations every year ($km^2$).

| National Zones | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| Valle d'Aosta | 0.04 | 0.04 | 0.04 | 0.05 | 0.04 | 0.05 |
| Piemonte | 0.98 | 1.03 | 1.09 | 1.16 | 1.15 | 1.25 |
| Liguria | 0.13 | 0.14 | 0.15 | 0.17 | 0.17 | 0.18 |
| Lombardia | 1.93 | 2.08 | 2.24 | 2.44 | 2.55 | 2.86 |
| Trentino Alto Adige | 0.40 | 0.45 | 0.46 | 0.48 | 0.44 | 0.46 |
| Veneto | 1.94 | 2.08 | 2.23 | 2.43 | 2.52 | 2.81 |
| Friuli Venezia Giulia | 0.62 | 0.64 | 0.67 | 0.71 | 0.72 | 0.77 |
| Emilia Romagna | 1.34 | 1.42 | 1.51 | 1.63 | 1.63 | 1.79 |
| Toscana | 0.69 | 0.73 | 0.77 | 0.82 | 0.82 | 0.90 |
| Umbria | 0.31 | 0.33 | 0.35 | 0.37 | 0.36 | 0.36 |
| Marche | 0.46 | 0.49 | 0.51 | 0.54 | 0.52 | 0.55 |
| Lazio | 0.91 | 0.98 | 1.05 | 1.14 | 1.18 | 1.27 |
| Abruzzo | 0.35 | 0.42 | 0.44 | 0.46 | 0.44 | 0.45 |
| Molise | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.09 |
| Campania | 0.58 | 0.62 | 0.66 | 0.71 | 0.72 | 0.78 |
| Puglia | 0.79 | 0.93 | 0.97 | 1.02 | 1.02 | 1.02 |
| Basilicata | 0.14 | 0.15 | 0.16 | 0.16 | 0.15 | 0.16 |
| Calabria | 0.47 | 0.52 | 0.55 | 0.58 | 0.56 | 0.59 |
| Sicilia | 0.98 | 1.09 | 1.15 | 1.22 | 1.24 | 1.30 |
| Sardegna | 0.67 | 0.73 | 0.76 | 0.80 | 0.79 | 0.81 |
| Northwest | 3.08 | 3.30 | 3.53 | 3.82 | 3.91 | 4.34 |
| Northeast | 4.30 | 4.59 | 4.88 | 5.25 | 5.30 | 5.82 |
| Centre | 2.36 | 2.54 | 2.69 | 2.87 | 2.89 | 3.08 |
| South | 2.42 | 2.73 | 2.86 | 3.03 | 2.98 | 3.09 |
| Islands | 1.66 | 1.83 | 1.91 | 2.02 | 2.02 | 2.10 |
| Total | 13.82 | 14.98 | 15.86 | 16.99 | 17.11 | 18.44 |

**Table 5.** Annual growth rates (%) of photovoltaic installations ($GR_{PhV}$) adopted for the forecasting analysis for each region.

| Regions | $GR_{PhV-1}$ | $GR_{PhV-2}$ | $GR_{PhV-3}$ | $GR_{PhV-4}$ |
|---|---|---|---|---|
| Valle d'Aosta | 5.4 | 5.6 | 6.5 | 4.3 |
| Piemonte | 6.6 | 6.9 | 7.5 | 5.7 |
| Liguria | 7.2 | 7.3 | 8.0 | 6.6 |
| Lombardia | 8.6 | 8.4 | 9.3 | 7.8 |
| Trentino Alto Adige | 4.0 | 4.5 | 5.4 | 2.7 |
| Veneto | 8.5 | 8.3 | 9.3 | 7.6 |
| Friuli Venezia Giulia | 5.3 | 5.6 | 5.8 | 4.9 |
| Emilia Romagna | 7.4 | 7.7 | 8.1 | 6.8 |
| Toscana | 6.3 | 6.4 | 7.2 | 5.4 |
| Umbria | 4.0 | 5.2 | 6.1 | 2.4 |
| Marche | 5.7 | 5.8 | 6.5 | 4.9 |
| Lazio | 7.9 | 8.2 | 8.7 | 7.3 |
| Abruzzo | 6.4 | 5.3 | 9.2 | 3.5 |
| Molise | 4.2 | 3.8 | 5.4 | 2.7 |
| Campania | 6.7 | 7.3 | 7.6 | 5.9 |
| Puglia | 6.9 | 5.5 | 9.7 | 3.5 |
| Basilicata | 4.6 | 4.6 | 6.4 | 2.5 |
| Calabria | 5.4 | 5.7 | 6.3 | 4.7 |
| Sicilia | 6.6 | 5.9 | 8.0 | 5.0 |
| Sardegna | 4.5 | 4.6 | 5.5 | 3.6 |
| Italy | 7.0 | 7.2 | 7.7 | 6.4 |

Finally, to take into account the improvements in photovoltaic technology over the years, a mean development rate was also estimated for each region. In particular, based on

the number of new installations and the total power of photovoltaic systems installed every year, the average power for each installation was assessed and development rates of this technology ($DR_{P\text{-}PhV}$) were evaluated as the relative difference between two consecutive years. Starting from these values, a mean $DR_{P\text{-}PhV}$ was assessed (Table 6).

**Table 6.** Annual development rates (%) of photovoltaic technology ($DR_{P\text{-}PhV}$) adopted for the forecasting analysis for each region.

| Regions | 2016–2017 | 2017–2018 | 2018–2019 | 2019–2020 | 2020–2021 | Mean |
|---|---|---|---|---|---|---|
| Valle d'Aosta | 5.6 | 5.3 | 6.8 | −1.3 | 9.1 | 5.1 |
| Piemonte | 12.5 | 0.0 | 11.1 | −10.0 | 11.1 | 4.9 |
| Liguria | 11.5 | 6.9 | 9.7 | 0.0 | 8.8 | 7.4 |
| Lombardia | 7.9 | 7.6 | 8.8 | 4.7 | 12.0 | 8.2 |
| Trentino Alto Adige | 12.5 | 4.4 | 3.2 | −9.3 | 4.5 | 3.1 |
| Veneto | 7.1 | 7.1 | 8.9 | 3.7 | 11.6 | 7.7 |
| Friuli Venezia Giulia | 2.4 | 4.7 | 5.9 | 1.4 | 6.9 | 4.3 |
| Emilia Romagna | 5.9 | 6.6 | 7.8 | 0.0 | 9.4 | 6.0 |
| Toscana | 6.5 | 5.4 | 6.4 | 0.0 | 9.6 | 5.6 |
| Umbria | 6.5 | 6.1 | 5.7 | −1.4 | 0.0 | 3.4 |
| Marche | 7.5 | 4.0 | 5.8 | −3.6 | 4.7 | 3.7 |
| Lazio | 8.7 | 7.0 | 8.0 | 3.9 | 7.5 | 7.0 |
| Abruzzo | 18.3 | 4.8 | 5.7 | −5.4 | 3.4 | 5.4 |
| Molise | 6.3 | 5.9 | 5.6 | −5.3 | 0.0 | 2.5 |
| Campania | 6.8 | 6.3 | 7.5 | 0.7 | 9.0 | 6.1 |
| Puglia | 18.2 | 4.3 | 5.6 | −0.5 | 0.0 | 5.5 |
| Basilicata | 6.9 | 3.2 | 3.1 | −6.1 | 3.2 | 2.1 |
| Calabria | 10.4 | 4.7 | 5.4 | −2.6 | 5.3 | 4.6 |
| Sicilia | 11.1 | 5.0 | 6.5 | 1.2 | 4.8 | 5.7 |
| Sardegna | 8.8 | 4.1 | 4.5 | −1.2 | 2.5 | 3.7 |
| Italy | 9.1 | 5.2 | 6.6 | −1.5 | 6.2 | 5.1 |

### *2.3. National Building Stock: Roof Surface Area Calculation*

One key point in the forecasting analysis lies in the roof surface area assessment, which used the roof surface area of existing buildings and is calculated using data provided by the National Institute of Statistics [5], which is available online. Considering the limited information and correlation provided by [5], such as the number of residential buildings per number of floors, the number of buildings per number of building units, and the number of building units per net surface range, the following steps were followed for the roof surface area calculations:

- Step 1: a correlation between the number of buildings per number of floors (the National Institute of Statistics groups data into "one floor", "two floors", "three floors", and "four and more floors") and the number of buildings per building units (data grouped into "one unit", "two units", "three or four units", "from five to eight units", "from nine to fifteen units", and "more than sixteen units") was attempted;
- Step 2: the total net surface area of building units was assessed by correlating data obtained from step 1 and the number of building units per specific net surface range provided by [5] (data groups into "$\leq$29 $m^2$", "30–39 $m^2$", "40–49 $m^2$", "50–59 $m^2$", "60–79 $m^2$", "80–99 $m^2$", "100–119 $m^2$", "120–149 $m^2$", and "$\geq$150 $m^2$");
- Step 3: for the buildings falling into the group "four or more floors" provided by [5], an average and weighted height was assessed varying the number of the floors in the 4–14 range based on the number of building units;
- Step 4: for each group of buildings ("one floor", "two floors", "three floors", and "four and more floors"), the total net surface area was assessed and divided for the height of the buildings, calculating the theoretical roof surface area of existing buildings.

According to [5], it was possible to perform this analysis by considering around 12 million residential buildings, of which almost 50% are on "two floors", around 24% on "three

floors", and just over 17% on "one floor". Buildings with "four or more floors" represent the minority of the sample (just under 10%). Furthermore, the number of building units for each building is highly variable, with a clear difference for single-family units (SFH—around 54% of the sample) and multi-family houses (MFH). Finally, the data highlights that buildings with more than nine building units are a small percentage of the sample (less than 5% overall), indicating a lower diffusion of this type of building.

To proceed with step 1, the following assumptions were made:

- buildings on "one floor" were considered buildings with only one building unit;
- buildings on "two floors" were associated with buildings from one to four building units;
- buildings on "three floors" were considered as buildings from two to eight building units;
- buildings on "four or more floors" were associated with buildings with more than four building units.

Based on these assumptions, around 31 million building units were correlated and grouped into the ranges, as shown in Table 7: around 21% of the sample falls into "one floor" (SFH), about 25% fall into "two floors" (around 8.5 million of the sample), whilst more than 40% fall into buildings with "four or more floors".

**Table 7.** Building units (grouped into "n. 1", "n. 2", "n. 3–4", "n. 5–8", "n. 9–15", and "n. ≥16") distribution (%): breakdown by geographical area in Italy, number of building floors ("one floor", "two floors", "three floors", and "four and more floors"), and building type (single-family house—SFH and multi-family house—MFH).

| | SFH | MFH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Zones** | **1 Floor** | **2 Floors** | | | **3 Floors** | | | **≥4 Floors** | | | |
| | **n. 1** | **n. 1** | **n. 2** | **n. 3–4** | **n. 2** | **n. 3–4** | **n. 5–8** | **n. 3–4** | **n. 5–8** | **n. 9–15** | **n. ≥16** |
| Piemonte | 0.3 | 1.5 | 0.3 | 0.1 | 0.9 | 0.3 | 0.8 | 0.7 | 0.1 | 1.0 | 1.7 |
| Valle d'Aosta | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 |
| Liguria | 0.1 | 0.3 | 0.2 | 0.0 | 0.2 | 0.1 | 0.4 | 0.3 | 0.0 | 0.5 | 1.1 |
| Lombardia | 0.4 | 1.7 | 1.1 | 1.5 | 1.3 | 0.8 | 2.1 | 0.5 | 0.3 | 2.2 | 3.4 |
| Trentino Alto Adige | 0.0 | 0.2 | 0.0 | 0.0 | 0.3 | 0.1 | 0.3 | 0.3 | 0.0 | 0.2 | 0.2 |
| Veneto | 0.3 | 1.5 | 0.8 | 0.9 | 0.9 | 0.4 | 0.9 | 0.2 | 0.2 | 0.9 | 0.8 |
| Friuli Venezia Giulia | 0.1 | 0.5 | 0.0 | 0.0 | 0.4 | 0.1 | 0.2 | 0.2 | 0.0 | 0.3 | 0.3 |
| Emilia Romagna | 0.2 | 1.0 | 0.6 | 0.4 | 0.7 | 0.4 | 1.2 | 0.7 | 0.1 | 1.2 | 1.2 |
| Toscana | 0.3 | 0.9 | 0.5 | 0.5 | 0.6 | 0.4 | 0.9 | 0.4 | 0.1 | 0.8 | 0.9 |
| Umbria | 0.1 | 0.3 | 0.1 | 0.0 | 0.2 | 0.1 | 0.2 | 0.2 | 0.0 | 0.1 | 0.1 |
| Marche | 0.1 | 0.4 | 0.1 | 0.0 | 0.4 | 0.2 | 0.4 | 0.4 | 0.0 | 0.3 | 0.3 |
| Lazio | 0.5 | 0.7 | 0.5 | 0.8 | 0.6 | 0.4 | 0.8 | 0.2 | 0.4 | 1.3 | 2.1 |
| Abruzzo | 0.1 | 0.5 | 0.1 | 0.0 | 0.4 | 0.1 | 0.3 | 0.3 | 0.0 | 0.3 | 0.3 |
| Molise | 0.0 | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 |
| Campania | 0.5 | 0.9 | 0.6 | 1.3 | 0.8 | 0.4 | 0.5 | 0.0 | 0.6 | 0.9 | 1.4 |
| Puglia | 1.4 | 0.5 | 0.5 | 1.1 | 0.6 | 0.0 | 0.0 | 0.0 | 0.8 | 0.8 | 1.0 |
| Basilicata | 0.1 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 |
| Calabria | 0.4 | 0.7 | 0.3 | 0.1 | 0.5 | 0.2 | 0.5 | 0.5 | 0.1 | 0.4 | 0.4 |
| Sicilia | 1.3 | 1.5 | 0.4 | 0.1 | 1.5 | 0.5 | 0.9 | 1.2 | 0.1 | 0.8 | 1.0 |
| Sardegna | 0.4 | 0.7 | 0.2 | 0.0 | 0.3 | 0.1 | 0.3 | 0.3 | 0.0 | 0.3 | 0.3 |
| Northwest | 0.8 | 3.5 | 1.6 | 1.6 | 2.6 | 1.3 | 3.2 | 1.5 | 0.4 | 3.8 | 6.3 |
| Northeast | 0.6 | 3.2 | 1.4 | 1.3 | 2.3 | 1.0 | 2.6 | 1.4 | 0.4 | 2.6 | 2.6 |
| Centre | 0.9 | 2.3 | 1.3 | 1.4 | 1.9 | 1.0 | 2.3 | 1.2 | 0.5 | 2.6 | 3.4 |
| South | 2.6 | 2.9 | 1.6 | 2.4 | 2.5 | 0.8 | 1.5 | 1.1 | 1.5 | 2.4 | 3.3 |
| Islands | 1.7 | 2.2 | 0.6 | 0.1 | 1.8 | 0.6 | 1.2 | 1.5 | 0.1 | 1.1 | 1.3 |
| Total | 6.7 | 14.3 | 7.9 | 3.7 | 9.7 | 5.2 | 12.4 | 9.3 | 1.4 | 12.5 | 16.9 |

The evaluated distribution was merged with the distribution of the sample per specific surface area ranges provided by the National Institute of Statistics (step 2), and a theoretical net surface area of building units was assessed by considering an average value for each

surface area range (step 3). An iteration analysis varying the number of floors for the buildings falling into the "four or more floors" group was carried out, calculating an average and weighted number of floors for this type of building equal to 5.48 m (step 4). A total roof surface area was assessed to be around 1350 km$^2$; finally, since no information regarding the inclination of the roofs is provided, an average pitch inclination of 25° was assumed, obtaining a total roof surface area of about 1490 km$^2$, which is considered as the roof surface area value for existing buildings. It is worth noting that the theoretical roof surface area can be considered a precautionary value as it was estimated starting from the net surface area of building units. Therefore, it could be possible that the actual surface area could also be higher than the estimated value. Furthermore, assuming that not all of the roofs have an optimal orientation for the installation of photovoltaic panels, the calculated roof surface area values have been further reduced. In this regard, it was assumed that only 30% of the surface area has suitable conditions for the installation of photovoltaic systems, reducing the available surface area to around 447 km$^2$ overall.

The percentage distribution of the sample from steps 2 and 3 for each surface area range is shown in Table 8, whilst the maximum theoretical roof surface areas and the reference roof surface areas adopted for the forecasting analysis are detailed in Table 9. More detailed information in Tables A1–A3 is reported in Appendix A.

**Table 8.** Net surface distribution (%) of building units (BU): breakdown for the geographical area of Italy (NW = Northwest, NE = Northeast, C = Centre, S = South, and I = Islands) and building type (single-family house—SFH and multi-family house—MFH).

| Building Type | Area | Net Surface Area Distribution of the Building Units (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ≤29 * | 30–39 | 40–49 | 50–59 | 60–79 | 80–99 | 100–119 | 120–149 | ≥150 |
| SFH | NW | 0.0 | 0.0 | 0.2 | 0.5 | 2.2 | 3.6 | 3.1 | 2.9 | 4.6 |
| | NE | 0.0 | 0.0 | 0.1 | 0.3 | 1.6 | 3.0 | 3.3 | 3.4 | 5.9 |
| | C | 0.0 | 0.0 | 0.1 | 0.3 | 1.6 | 2.9 | 2.8 | 2.5 | 3.6 |
| | S | 0.0 | 0.1 | 0.2 | 0.5 | 2.6 | 6.2 | 6.5 | 6.0 | 7.9 |
| | I | 0.0 | 0.0 | 0.2 | 0.4 | 1.8 | 3.9 | 4.8 | 4.6 | 5.6 |
| MFH (2 floors) | NW | 0.0 | 0.3 | 1.0 | 1.8 | 6.4 | 9.3 | 6.8 | 5.7 | 7.7 |
| | NE | 0.0 | 0.1 | 0.3 | 0.5 | 2.3 | 3.7 | 3.4 | 3.2 | 5.1 |
| | C | 0.0 | 0.1 | 0.4 | 0.7 | 2.8 | 3.8 | 2.9 | 2.3 | 3.0 |
| | S | 0.0 | 0.2 | 0.4 | 0.7 | 3.0 | 5.7 | 4.8 | 3.6 | 4.1 |
| | I | 0.0 | 0.0 | 0.1 | 0.1 | 0.4 | 0.8 | 0.8 | 0.7 | 0.7 |
| MFH (3 floors) | NW | 0.0 | 0.3 | 1.1 | 1.9 | 6.9 | 9.8 | 7.2 | 6.0 | 8.2 |
| | NE | 0.0 | 0.1 | 0.3 | 0.6 | 2.5 | 4.0 | 3.7 | 3.3 | 5.1 |
| | C | 0.0 | 0.1 | 0.4 | 0.7 | 2.6 | 3.6 | 2.8 | 2.2 | 2.9 |
| | S | 0.0 | 0.1 | 0.2 | 0.4 | 1.5 | 2.8 | 2.4 | 1.8 | 2.1 |
| | I | 0.0 | 0.1 | 0.2 | 0.4 | 1.5 | 2.7 | 2.9 | 2.2 | 2.4 |
| MFH (≥4 floors) | NW | 0.0 | 0.3 | 1.1 | 1.9 | 7.0 | 9.9 | 7.2 | 6.0 | 8.3 |
| | NE | 0.0 | 0.1 | 0.3 | 0.5 | 2.1 | 3.3 | 2.9 | 2.6 | 4.0 |
| | C | 0.0 | 0.1 | 0.4 | 0.7 | 2.9 | 4.0 | 3.1 | 2.4 | 3.1 |
| | S | 0.0 | 0.1 | 0.3 | 0.5 | 2.0 | 3.9 | 3.3 | 2.5 | 2.9 |
| | I | 0.0 | 0.1 | 0.2 | 0.3 | 1.2 | 2.2 | 2.3 | 1.8 | 1.9 |

* Order of magnitude of the values shown in this column is around 0.0043 on average.

**Table 9.** Assessment of the mean roof surface area (km$^2$) of existing buildings by varying the roof pitch.

| Zones | SFH | MFH | Total | 25° | 30% |
|---|---|---|---|---|---|
| Piemonte | 41.85 | 46.74 | 88.58 | 97.74 | 29.32 |
| Valle d'Aosta | 1.19 | 0.07 | 1.26 | 1.39 | 0.42 |
| Liguria | 8.08 | 7.44 | 15.53 | 17.13 | 5.14 |
| Lombardia | 51.63 | 251.99 | 303.62 | 335.01 | 100.50 |

**Table 9.** *Cont.*

| Zones | SFH | MFH | Total | 25° | 30% |
|---|---|---|---|---|---|
| Trentino Alto Adige | 5.52 | 2.76 | 8.28 | 9.13 | 2.74 |
| Veneto | 53.63 | 71.34 | 124.97 | 137.89 | 41.37 |
| Friuli Venezia Giulia | 16.61 | 3.68 | 20.30 | 22.40 | 6.72 |
| Emilia Romagna | 30.24 | 58.96 | 89.20 | 98.42 | 29.53 |
| Toscana | 29.55 | 39.96 | 69.51 | 76.69 | 23.01 |
| Umbria | 8.74 | 2.11 | 10.85 | 11.98 | 3.59 |
| Marche | 11.89 | 6.56 | 18.45 | 20.36 | 6.11 |
| Lazio | 32.90 | 71.37 | 104.27 | 115.05 | 34.51 |
| Abruzzo | 18.00 | 4.71 | 22.72 | 25.06 | 7.52 |
| Molise | 5.73 | 0.24 | 5.97 | 6.59 | 1.98 |
| Campania | 38.42 | 66.67 | 105.09 | 115.95 | 34.78 |
| Puglia | 72.93 | 38.16 | 111.09 | 122.58 | 36.77 |
| Basilicata | 8.41 | 0.85 | 9.26 | 10.22 | 3.07 |
| Calabria | 36.59 | 11.74 | 48.33 | 53.32 | 16.00 |
| Sicilia | 89.58 | 60.16 | 149.74 | 165.22 | 49.57 |
| Sardegna | 37.82 | 6.63 | 44.45 | 49.04 | 14.71 |
| Northwest | 102.75 | 306.24 | 408.99 | 451.27 | 135.38 |
| Northeast | 106.01 | 136.74 | 242.75 | 267.84 | 80.35 |
| Centre | 83.09 | 119.99 | 203.08 | 224.07 | 67.22 |
| South | 180.09 | 122.36 | 302.45 | 333.72 | 100.12 |
| Islands | 127.40 | 66.79 | 194.18 | 214.26 | 64.28 |
| Total | 599.33 | 752.13 | 1351.45 | 1491.16 | 447.35 |

## 3. Results and Discussion

### *3.1. Photovoltaic Energy Production: Annual vs. Monthly Calculations*

As stated, all of the national reports on photovoltaic systems [14–19] provided disaggregated data only on an annual basis, whilst aggregate data (i.e., including all of the sectors) is also provided monthly. The electrical energy consumption is only provided on an annual basis [6–13] for each sector. As the impact of the photovoltaic system on the residential sector was studied in this work, it was only possible to take into account disaggregated data on an annual basis. However, the energy production of photovoltaic systems, as well as the energy requirements of the residential sector, are strongly dependent on the month of the year and location. For that reason, a preliminary analysis was performed aimed at checking the reliability of the annual forecasting concerning monthly forecasting because of the unavailability of some monthly data. This analysis was only possible for photovoltaic energy production since this monthly data can be obtained from the solar atlas provided by the Energy Services Manager [41].

For this preliminary analysis, the following assumptions were made:

1. The energy production per $m^2$ of a photovoltaic system with monthly steps is assessed according to the solar atlas provided by the Energy Services Manager for each region and investigated year [41];
2. Since national reports [14–19] provide only the number of new installations with annual steps, it was equally shared by the days of each month. The same assumption was made for the installed power since national reports did not provide any information on a monthly step.

Based on these assumptions (the monthly energy production, the number of new installations, and the power of photovoltaic systems installed on the roof of buildings), it was possible to carry out a monthly forecasting analysis for each region up to 2050. It was performed with the same approach adopted for the annual analysis, i.e., considering monthly growth rates for the number of new installations. Annual results estimated adopting monthly steps were thus compared to that returned on the annual basis to check the reliability of the two approaches.

The energy production comparison assessed with an annual or monthly approach for each region and year is shown in Figure 2. The annual estimated energy production starting from the monthly step is reported on the ordinate axis, whilst that on the annual basis is shown on the abscissa. It is worth noting that a little difference can be highlighted by adopting these two approaches; greater differences were found for the years 2017 and 2021, although this difference is around ±10% in the larger energy-producing regions.

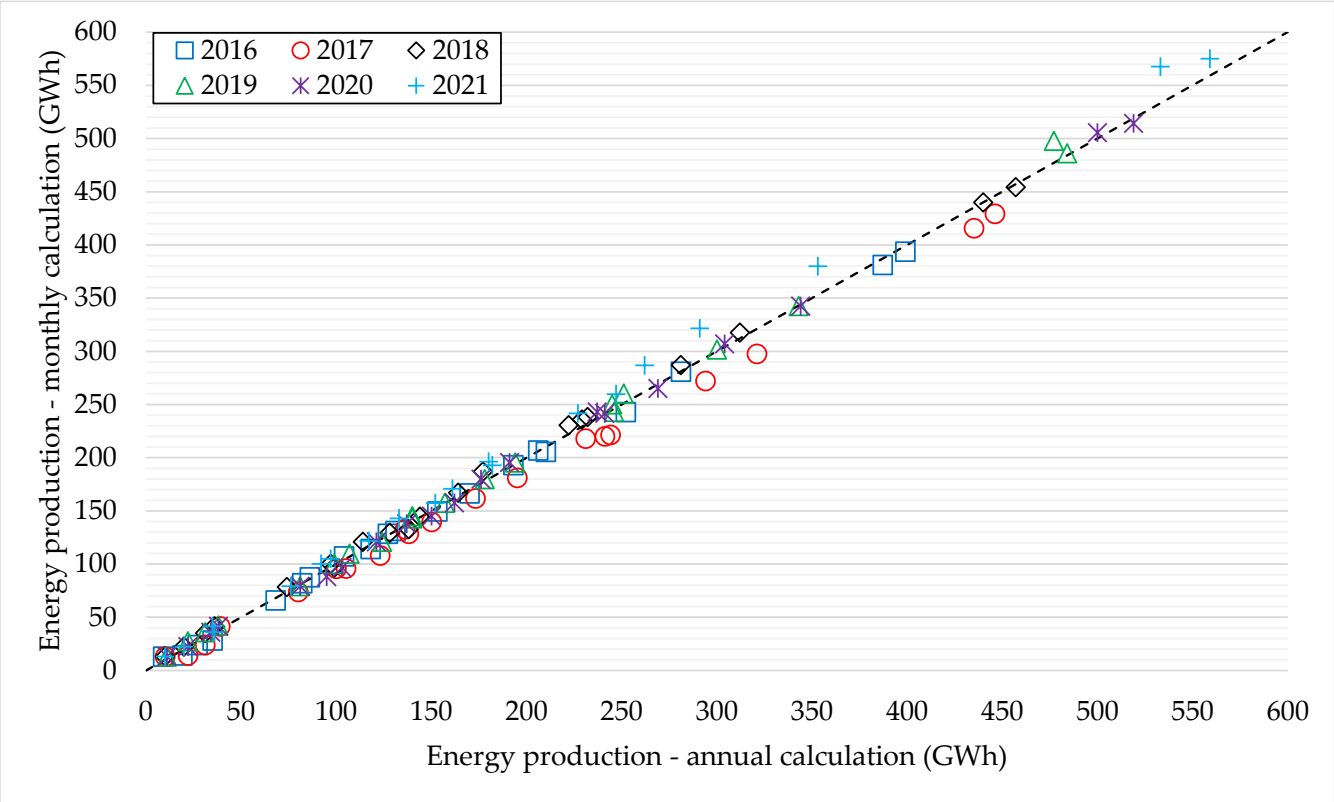


**Figure 2.** Comparison of the energy production of photovoltaic systems: annual vs. monthly calculation.

This result can be affected by the assumptions made in this work; however, the lack of information on the number of new installations every month meant that it was not possible to perform a more accurate analysis. Nevertheless, although the outcomes on an annual basis are slightly lower than those on a monthly basis, they can be considered reliable and precautionary. It means that it is possible that the energy production of the photovoltaic systems could be even greater than the estimated values. According to this result, the forecasting analysis on an annual basis can be considered a cautionary scenario.

### *3.2. Photovoltaic Energy Forecasting*

As already stated in previous sections, the forecasting analysis started in 2022 assuming the number of new installations of photovoltaic panels to be equal to the mean value found in the previous investigated years, as well as the photovoltaic power and energy production. Similarly, a mean value of energy consumption was also adopted. Based on these average values, using values from 2022 as the reference values, as detailed in Table 10, specific annual growth rates associated with the energy consumption of the residential sector ($GR_{EC}$) were applied to calculate the outgoing energy consumption in addition to the annual growth rates of the number of new installations of photovoltaic panels ($GR_{PhV}$), as already described in Table 8.

**Table 10.** Mean values for the photovoltaic systems in Italy: number of installations, power, energy production, and net surface area required for each installation.

| National Zones | Number (-) | Power (kW) | Energy (kWh/kW) | Available Roof Surface ($km^2$) | Energy Consumption (kWh) | $GR_{EC}$ (%) |
|---|---|---|---|---|---|---|
| Valle d'Aosta | 1862.0 | 9.2 | 1111.6 | 0.42 | 172.3 | −1.36 |
| Piemonte | 46,366.3 | 224.5 | 1036.6 | 29.32 | 4566.1 | −0.44 |
| Liguria | 7497.5 | 31.8 | 998.7 | 5.14 | 1701.6 | −0.54 |
| Lombardia | 107,763.7 | 475.2 | 978.3 | 100.50 | 11,310.2 | 0.01 |
| Trentino Alto Adige | 18,485.7 | 90.2 | 1053.0 | 2.74 | 1158.2 | −0.64 |
| Veneto | 103,018.2 | 472.2 | 1010.5 | 41.37 | 5574.6 | 0.54 |
| Friuli Venezia Giulia | 29,466.8 | 138.8 | 1013.1 | 6.72 | 1373.8 | 0.35 |
| Emilia Romagna | 71,134.0 | 314.2 | 1039.1 | 29.53 | 5142.6 | 0.01 |
| Toscana | 35,826.5 | 159.5 | 1075.6 | 23.01 | 4097.5 | 0.15 |
| Umbria | 15,085.0 | 69.7 | 1101.9 | 3.59 | 926.5 | 0.19 |
| Marche | 21,954.5 | 104.0 | 1127.9 | 6.11 | 1545.0 | 0.32 |
| Lazio | 49,092.5 | 220.2 | 1110.4 | 34.51 | 6597.1 | −0.61 |
| Abruzzo | 16,200.8 | 85.8 | 1152.8 | 7.52 | 1307.1 | 0.22 |
| Molise | 3101.3 | 17.7 | 1180.7 | 1.98 | 281.7 | −0.19 |
| Campania | 26,685.8 | 137.5 | 1100.3 | 34.78 | 5412.0 | 0.47 |
| Puglia | 38,538.7 | 193.7 | 1189.2 | 36.77 | 4122.7 | 0.92 |
| Basilicata | 5686.3 | 31.3 | 1176.8 | 3.07 | 497.2 | 0.24 |
| Calabria | 19,982.0 | 110.7 | 1198.5 | 16.00 | 2024.9 | 0.34 |
| Sicilia | 44,735.5 | 235.2 | 1224.9 | 49.57 | 5530.7 | 0.87 |
| Sardegna | 32,236.7 | 153.5 | 1204.6 | 14.71 | 2181.4 | 1.03 |
| Northwest | 163,489.5 | 740.7 | 1031.3 | 135.4 | 17,750.1 | −0.58 |
| Northeast | 222,104.7 | 1015.3 | 1028.9 | 80.4 | 13,249.1 | 0.06 |
| Centre | 121,958.5 | 553.3 | 1103.9 | 67.2 | 13,166.1 | 0.01 |
| South | 110,195.0 | 576.7 | 1166.4 | 100.1 | 13,645.5 | 0.33 |
| Islands | 76,972.2 | 388.7 | 1214.7 | 64.3 | 7712.1 | 0.95 |
| Total | 694,719.8 | 3274.7 | 1104.2 | 447.3 | 65,522.8 | 0.09 |

The results for estimated photovoltaic systems power output by 2050 are shown in Figure 3 whilst Figure 4 displays the results relating to the theoretical optimal roof surface area required by the photovoltaic systems by 2050. The results give an interesting insight, highlighting the greatest impact of photovoltaic panels in specific zones of Italy. From all of the adopted scenarios, the most promising zone could be the Northeast zone of Italy mainly due to the important contribution provided by the Veneto (which affects the photovoltaic power by about 59%) and Emilia Romagna regions (which affects the photovoltaic power by about 29%). In this zone, the most probable scenario ($GR_{PhV-2}$) could potentially recognize more than 9 GW of photovoltaic power by 2050, requiring a little less than 70% of the available roof surface of this zones. Even in the most conservative scenario ($GR_{PhV-4}$) it could be possible to reach 7 GW of photovoltaic power output by 2050, confirming that this zone is the most promisingly productive areas in Italy. In the most promising scenario ($GR_{PhV-3}$), 11 GW of photovoltaic power output by 2050 could potentially be achieved; however, it could require almost 80% of the available roof surface area. Moreover, this scenario is closely linked to the use of specific incentive systems such as the Superbonus, making it one of the more improbable scenarios.

The greatest potential can be highlighted in the Northwest and in the South zones, where less than 30–40% of the available roof surface could be used. In these zones, a photovoltaic power output of 7.0 GW (both Northwest and South) could potentially be achieved in the most promising scenario ($GR_{PhV-3}$), although values of 5.5 GW (Northwest) and 4.0 GW (South) seem to be most probable ($GR_{PhV-2}$), corresponding to less than 30% of the available roof surface area in those zones.

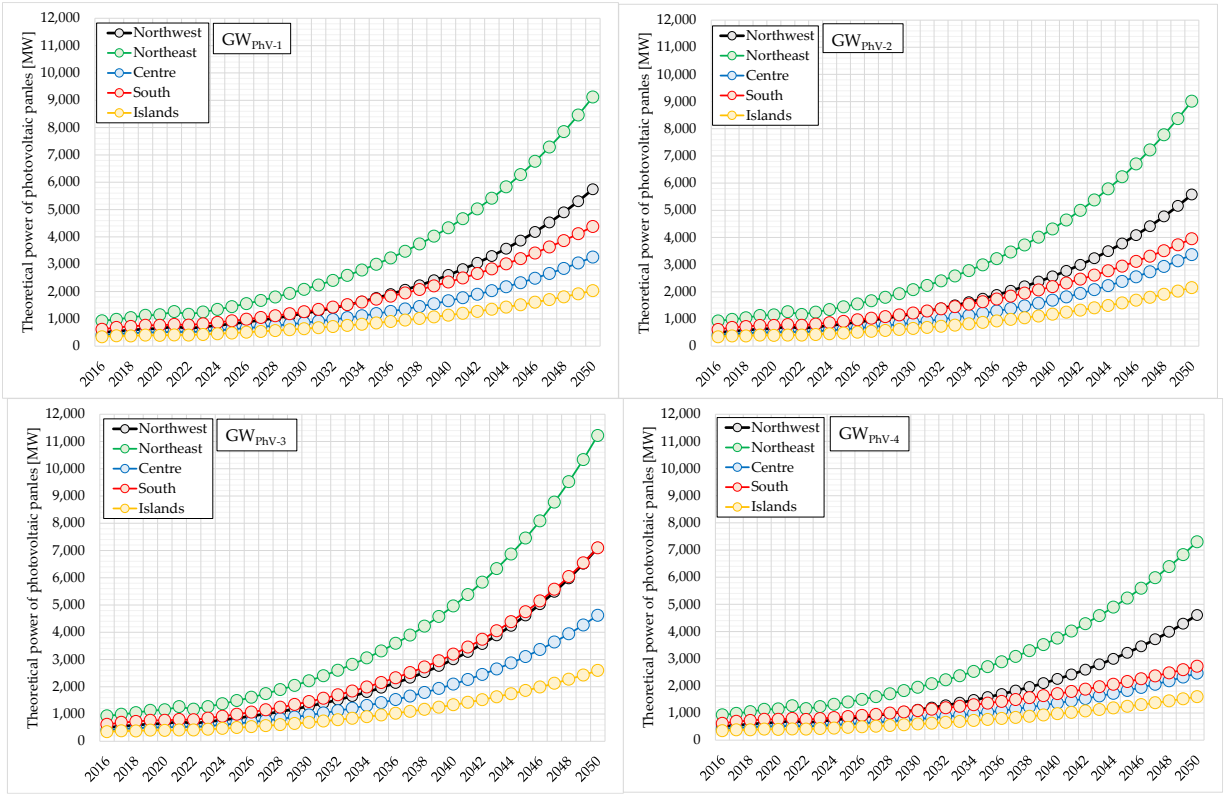


**Figure 3.** Power (MW) of photovoltaic panels: forecasting analysis over the years to 2050 for all of the national zones adopted in this study.

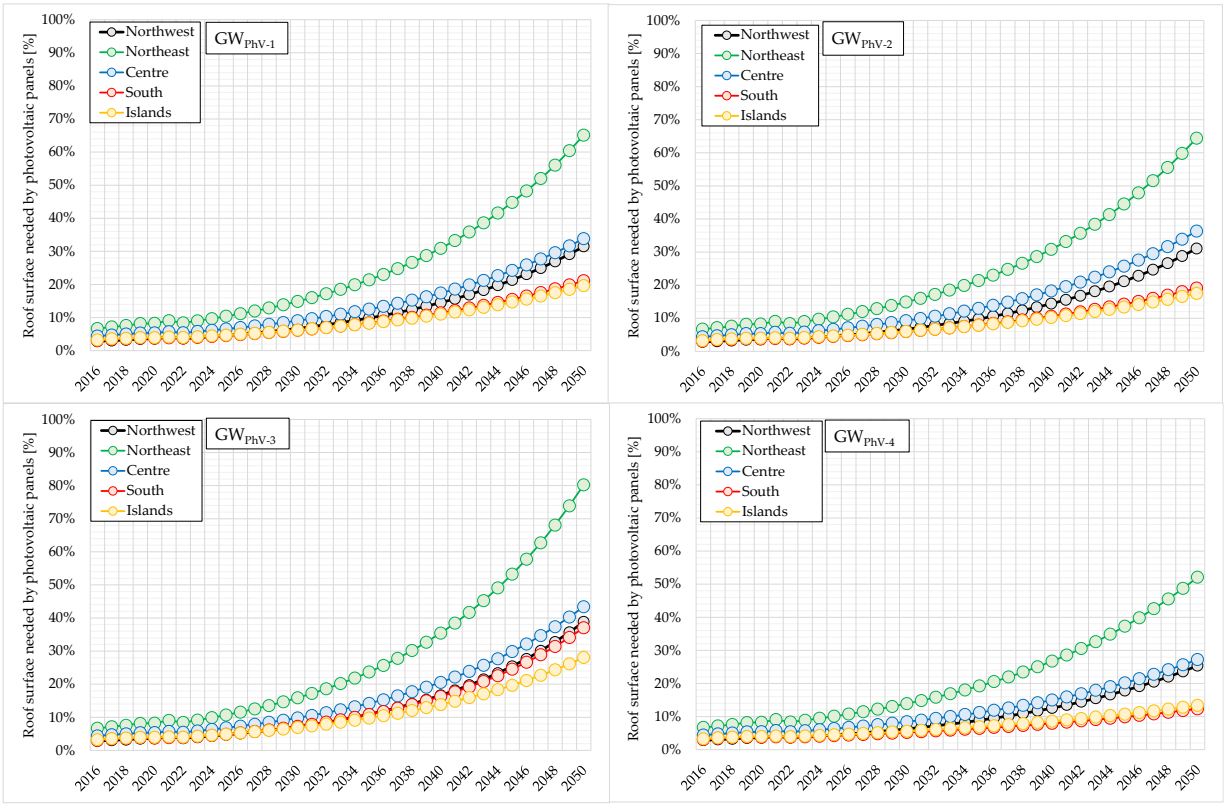


**Figure 4.** The theoretical roof surface area (%) required by photovoltaic panels: forecasting analysis over the years to 2050 for all of the national zones adopted in this study.

Similarly, the Centre zone showed significant room for flexibility since around 60–70% of the roof surface area would remain available. On the other hand, the Islands zone showed the least potential photovoltaic power output by 2050 due to the limited use of roof surfaces.

All of these scenarios confirmed a less marked growth for the central and southern regions of Italy, highlighting the need for specific incentive systems in those zones if more than the 5 GW threshold is to be exceeded by 2050.

It is worth noting that all of these scenarios could be feasible and technically possible since they could require less roof surface area than that estimated. Only for the Northeast area, the analyzed scenarios may not be feasible if greater incentives were adopted due to the smaller roof surface area available in that zone. According to these results, overall, it could be possible to reach around 6 GW of photovoltaic power output by 2030 if the moderate scenarios were considered ($GR_{PhV\text{-}1}$ and $GR_{PhV\text{-}2}$), i.e., 11.5% of the national goal, or a little bit more than 6.5 GW in the most promising scenario ($GR_{PhV\text{-}3}$ corresponding to about 12.7% of the national goal). In the most conservative scenario ($GR_{PhV\text{-}4}$), it could be possible to reach around 5.5 GW of photovoltaic power by 2030 overall, corresponding to about 10.5% of the national goal. The evaluated trends confirm the need for specific national incentives to increase the number of photovoltaic installations by 2030.

The energy produced and supplied by photovoltaic systems, with the respect to the electrical energy consumption of the building stock, was thus analyzed; the comparison is shown in Figures 5–9 for each considered zone (disaggregated data are reported in Appendix A). The energy required for the residential sector was assessed over the year by adopting the estimated mean $GR_{EC}$, as reported in Table 10.

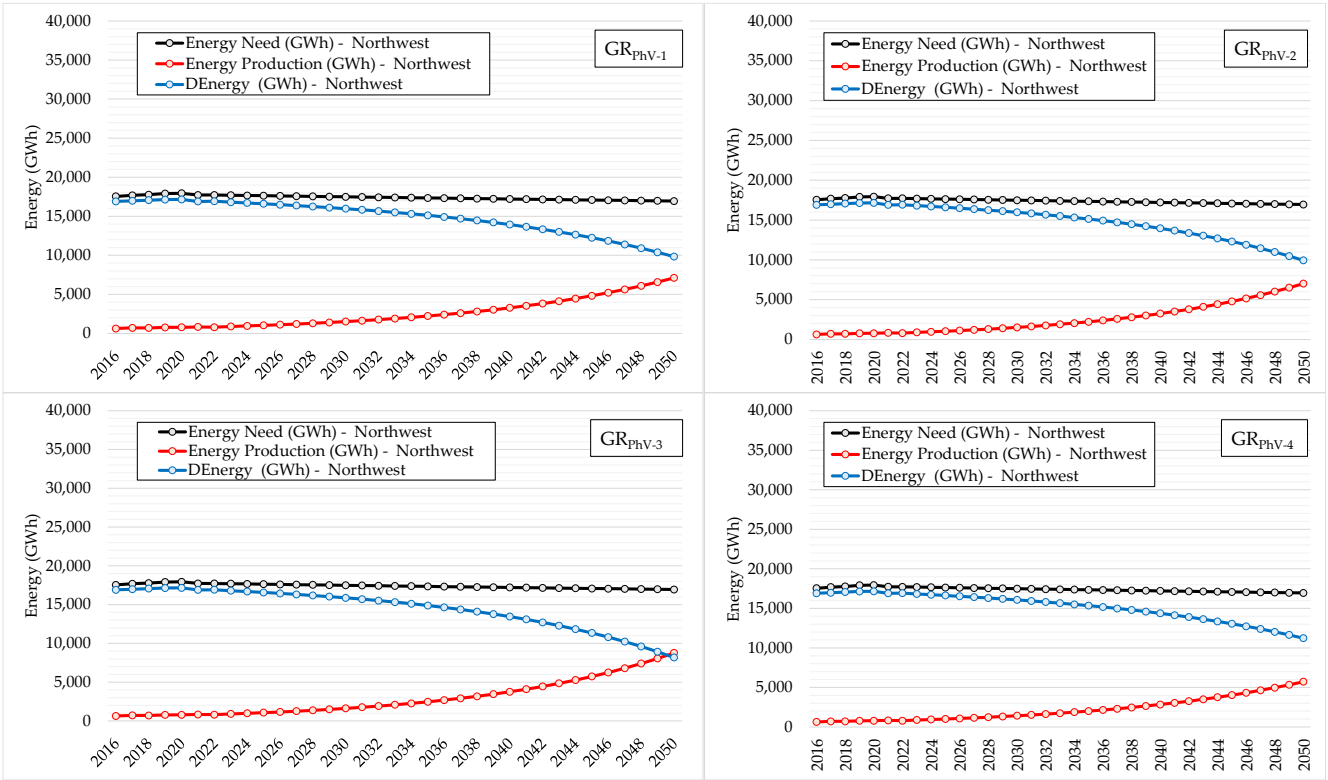


**Figure 5.** Energy requirements for the buildings sector, energy production, and energy requirements potentially met by photovoltaic panels by 2050 for various growth rates: the Northwest area of Italy.

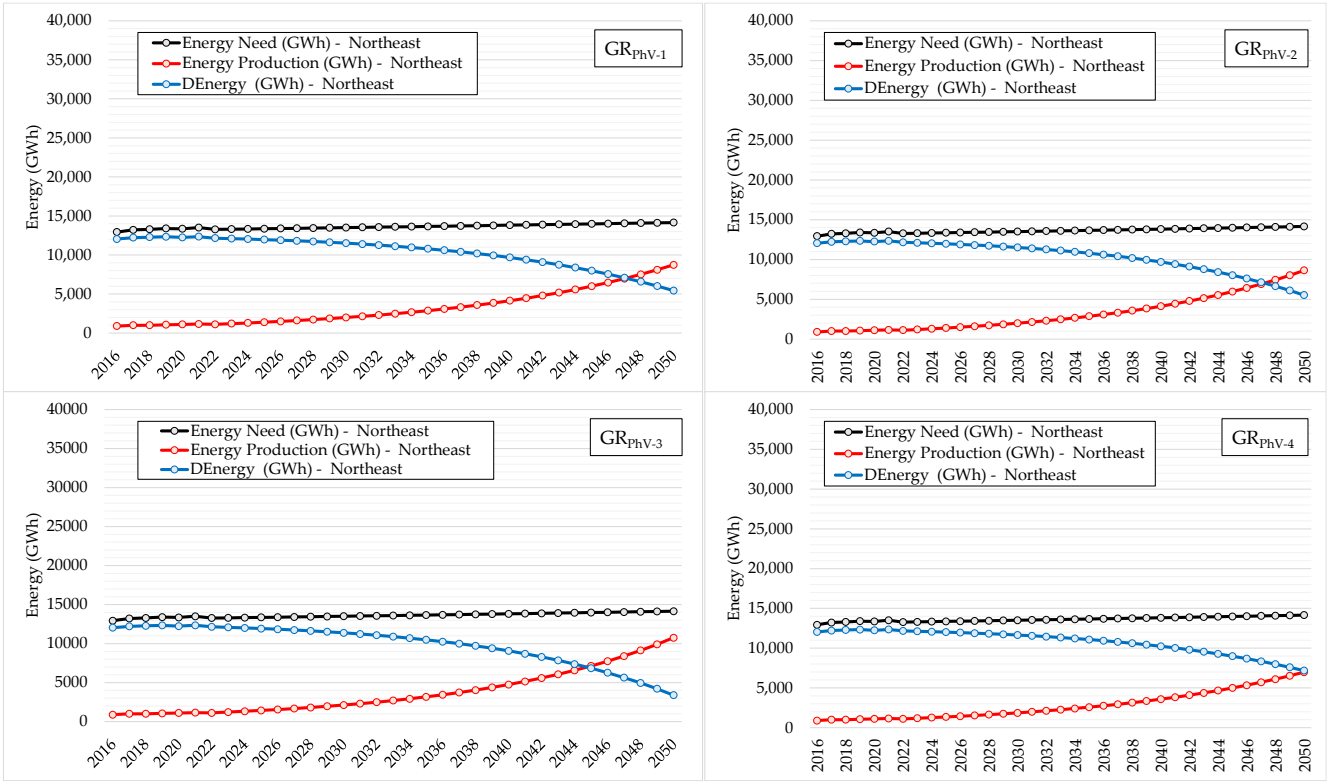


**Figure 6.** Energy requirements for the buildings sector, energy production, and energy requirements potentially met by photovoltaic panels by 2050 for various growth rates: the Northeast area of Italy.

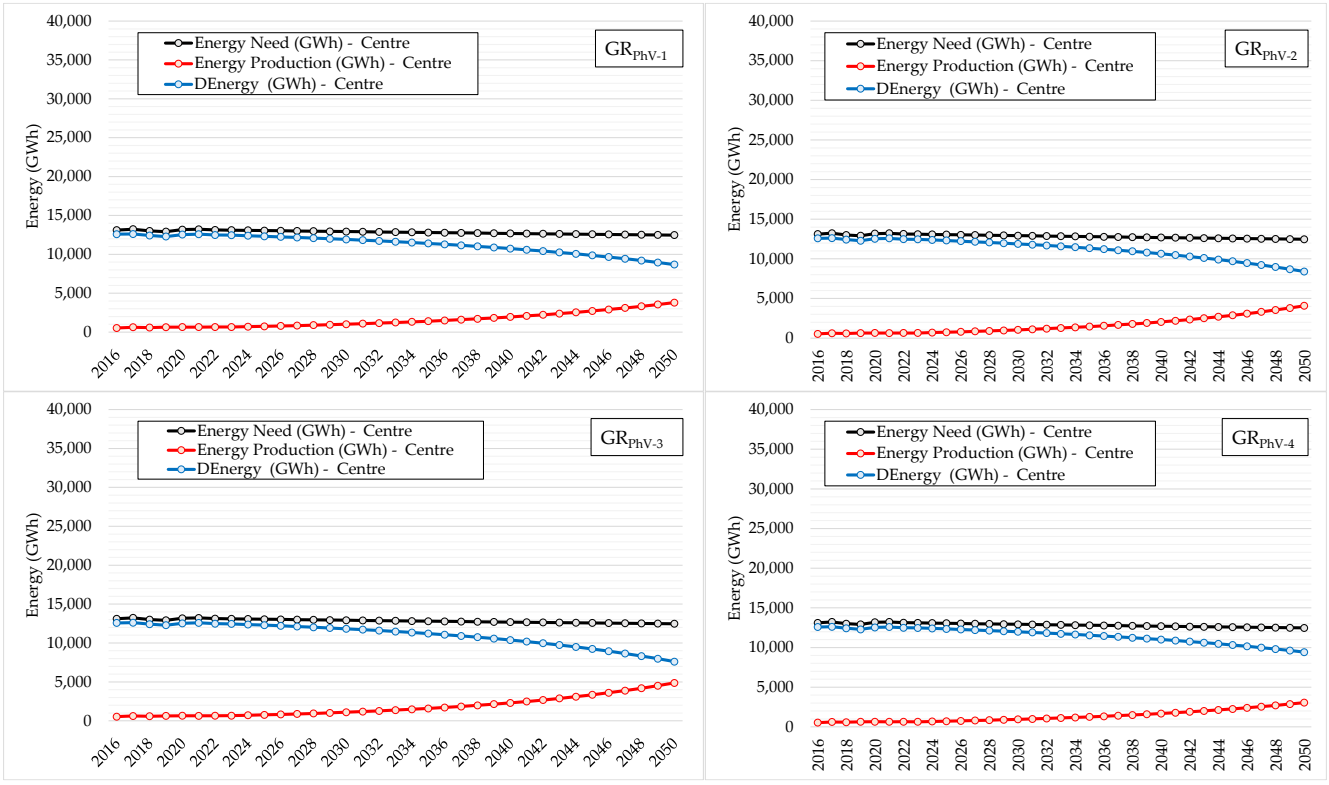


**Figure 7.** Energy requirements for the buildings sector, energy production, and energy requirements potentially met by photovoltaic panels by 2050 for various growth rates: the central area of Italy.

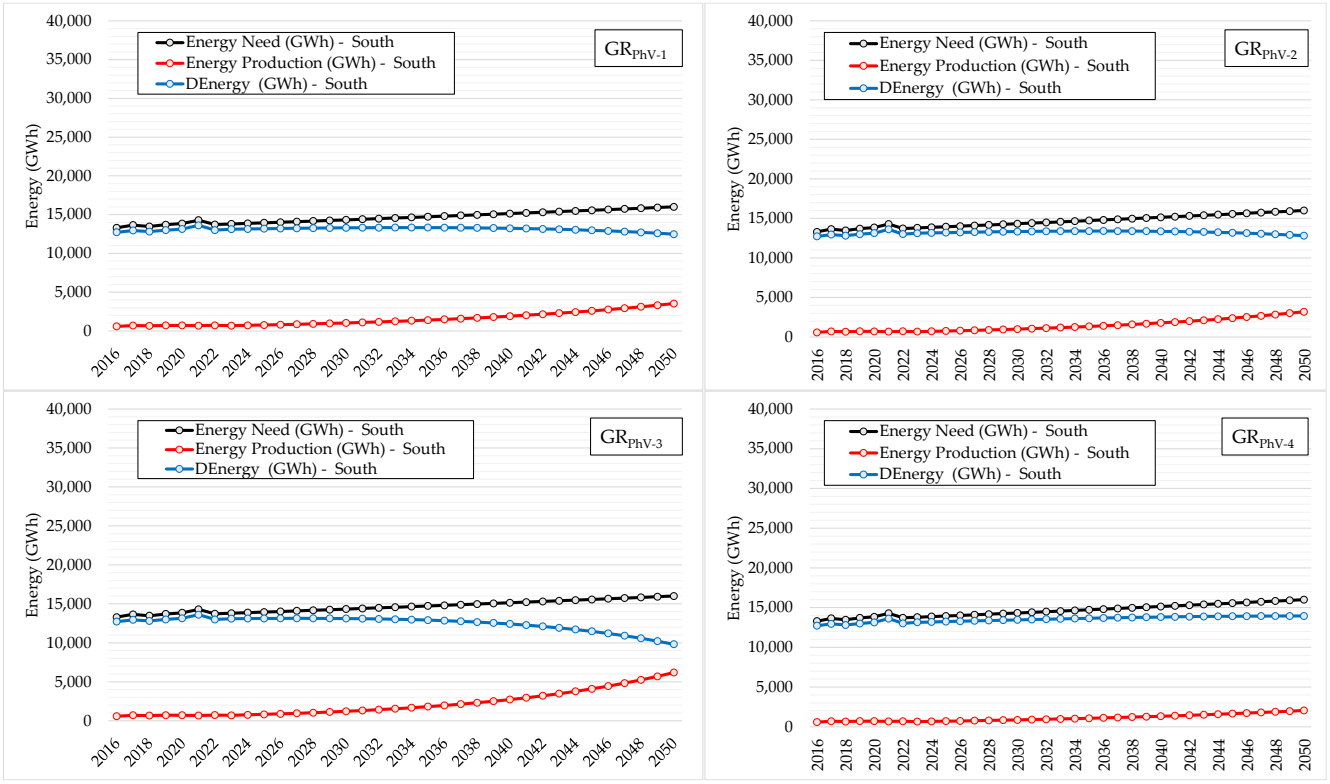


**Figure 8.** Energy requirements for the buildings sector, energy production, and energy requirements potentially met by photovoltaic panels by 2050 for various growth rates: the South area of Italy.

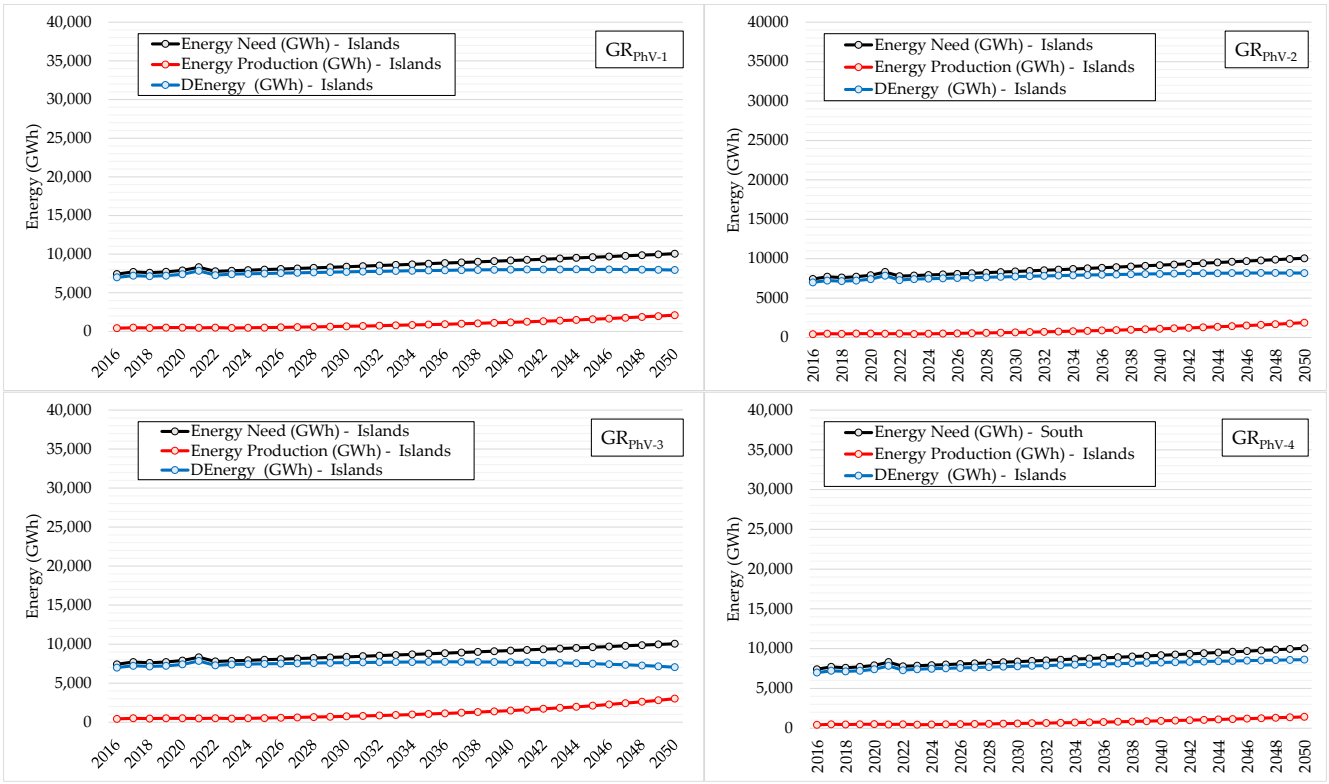


**Figure 9.** Energy requirements for the buildings sector, energy production, and energy requirements potentially met by photovoltaic panels by 2050 for various growth rates: the Islands of Italy.

Relevant findings can be highlighted in these figures:

1. Northwest zone: the energy supplied by photovoltaic panels could potentially exceed 5500 GWh in all of the $GR_{PhV}$ scenarios, allowing 40% to 50% of the electrical energy requirements by the building stock to be met, depending on the growth rate. It is worth noting that the blue lines in Figures 5–9 (representing the electrical energy to be covered by other energy sources) always have a downward concavity, indicating the good impact of these technologies already in this zone;
2. Northeast zone: the energy supplied by photovoltaic panels could potentially reach 7100 GWh even with low growth rates ($GR_{PhV-4}$), covering more than 50% of the predicted electrical energy requirements of the building stock by 2050 (the red line crosses the blue line). Moreover, in the most promising scenario ($GR_{PhV-3}$), the energy produced by photovoltaic panels could potentially reach more than 10,000 GWh, meeting more than 74% of electrical energy requirements;
3. Centre zone: although a smaller growth than in the northern area of Italy, it could be possible to meet 27–39% of the electrical energy requirements of the building stock by 2050. In that case, the most probable scenarios ($GR_{PhV-1}$ and $GR_{PhV-2}$) showed an energy coverage of 30–32% by achieving a potential energy production of around 3700–4000 GWh. However, these results pointed out that it could be necessary to take specific energy actions to reach the 50% threshold;
4. South zone: a completely different trend can be observed in this zone, which could underline possible issues of these regions to achieve the national target by 2050, where Puglia and Campania alone could produce more than 65% of the whole photovoltaic energy production. Nevertheless, the energy production would not exceed 6200 GWh, even in the most optimistic scenario ($GR_{PhV-3}$), which would allow the meeting of 38% of the predicted electrical energy requirements of the building stock. The evaluated trends highlighted significant issues for all of these regions mainly due to the limited number of installations recorded to date. In this case, it could also be necessary to implement additional actions to reach the 50% threshold;
5. Islands: similar to the South zone, the results have also underlined how far away the target is for the Islands zone, even if the Sicilia region alone could produce more than 1200–1500 GWh on average. The produced energy in that zone could allow between 13% ($GR_{PhV-4}$) and 28% ($GR_{PhV-3}$) of electrical energy requirements to be met, with an average and most probable outcome of 19–20%; therefore, additional specific energy actions should also be considered to reach the 50% threshold in this area.

As stated, all of the scenarios are potentially feasible since the required roof surface area would always be less than the estimated value (equal to around 450 $km^2$ overall). In fact, only in the Northeast area of Italy, could almost 80% of the roof surface be required, whilst, in all of the other zones, relevant room for improvement can be highlighted. In particular, when considering the produced energy and the available roof surface area, the northwestern area seems to be the area with the greatest power output potential, an area already widely distributed with this technology.

Furthermore, it is pertinent to underscore that, theoretically, the installable power on the roof surface areas (the estimated roof surface area could be around 450 $km^2$) could exceed 72 GW, enabling the production of over 79,000 GWh of energy. When compared to national objectives, namely a 55% reduction in emissions and the installation of 52 GW of new photovoltaic capacity by 2030, these objectives may potentially be achievable solely through the utilization of existing building roof surface areas, without the need for additional land use. However, the analyses have revealed the necessity of a region-specific incentive system tailored to the real potential, in terms of available surface area.

In addition to this cautionary scenario, a further analysis was performed in which the development rate of photovoltaic technology was also taken into account. For this analysis, the mean $DR_{P\text{-}PhV}$ defined in Table 6 was considered for each region. A comparison between the two forecasting analyses (with and without considering $DR_{P\text{-}PhV}$) was, therefore, carried out. The results shown in Table 11 are for two representative years (2030 and 2050) and the

average scenario ($GW_{PhV-2}$), highlighting that further development of this technology could help to reach a higher energy production by 2050 (around 26,000 GWh), i.e., increasing potential energy production by around 6% overall.

**Table 11.** Comparison between the energy production with and without considering the development rates of photovoltaic power ($GR_{P-PhV}$), i.e., with and without taking into account the predicted improvements in photovoltaic technology.

| National Zones | Energy Forecasting without $DR_{P-PhV}$ | | Energy Forecasting with $DR_{P-PhV}$ | |
|---|---|---|---|---|
| | 2030 | 2050 | 2030 | 2050 |
| Northwest | 1513.8 | 7016.7 | 1623.3 | 7537.5 |
| Northeast | 1994.5 | 8630.8 | 2122.5 | 9207.1 |
| Centre | 1039.4 | 4071.6 | 1098.3 | 4313.8 |
| South | 994.7 | 3188.1 | 1046.7 | 3358.6 |
| Islands | 644.8 | 1875.0 | 676.9 | 1970.5 |
| Italy | 6187.2 | 24,782.2 | 6567.7 | 26,387.4 |

Nevertheless, since the developments of this technology in the future are neither available nor foreseeable, the forecasting analysis carried out without $DR_{P-PhV}$ can be considered a more conservative scenario.

In this light, a new index has been introduced, namely the regional potential index (RPI), defined as the ratio between the photovoltaic power installed by three chosen reference years (2021, 2030, and 2050) and the theoretical maximum that could be installed on the calculated optimal roof surface area (around 450 $km^2$). For this analysis, the photovoltaic forecasting results with $GR_{PhV-2}$ were considered since it is the average trend in many national regions.

The results of the RPI assessment are reported in Figure 10, where the blue, red, and green lines are the assessed RPI for each region by 2021 (actual situation), 2030, and 2050. It is worth noting that the closer the RPI gets to 0%, the greater the photovoltaic potential of the region, i.e., much of the calculated roof surface area could still be available for new installations.

The figure shows that the RPI could potentially be lower than 40% by 2050 in all of the southern regions, reflecting their great potential to realize new installations also in the following years. Many northern and central regions have an RPI closer to or greater than 40%; in particular, the Veneto region reaches an RPI in the order of 90%, indicating the possible saturation of the roof surface area a few years after 2050. It is worth noting that although the different potential of the regions, in terms of the available roof surface area, all of the northern and central regions have shown a similar trend in RPI, indicating similar actions in using and placing photovoltaic panels based on their energy requirements and potential. On the other hand, the South and Islands regions have shown a greater potential from 2050 (RPI lower than 30–40%), highlighting a currently lower photovoltaic diffusion in these zones. Furthermore, a greater gap between the 2030 and 2050 lines can also be observed but only in a few regions (such as Veneto and Marche); this trend could indicate that in those regions, the growth rate of new photovoltaic installations could be more marked (tending more towards an exponential rather than linear trend). On the other hand, in all other regions, the smaller differences between these two lines could indicate a greater need to adopt appropriate incentive actions to increase the number of new installations.

It is worth noting that none of the analyses took into account the effects of climatic change. As already known, climatic change can significantly affect the productivity of photovoltaic panels; however, it is difficult to understand or forecast these effects due to various environmental factors. For instance, increased temperatures and extreme weather events, such as droughts, floods, and storms, could reduce photovoltaic efficiency. Dust and air pollution on the surface of solar panels can reduce their ability to absorb sunlight and convert it into electricity. Furthermore, changes in cloud cover and atmospheric conditions can impact the amount and intensity of sunlight that reaches the panels, resulting in a

decrease in their overall productivity. All of these factors can have a significant impact on the productivity of photovoltaic panels and should be considered when evaluating the potential effects of climate change on renewable energy production.

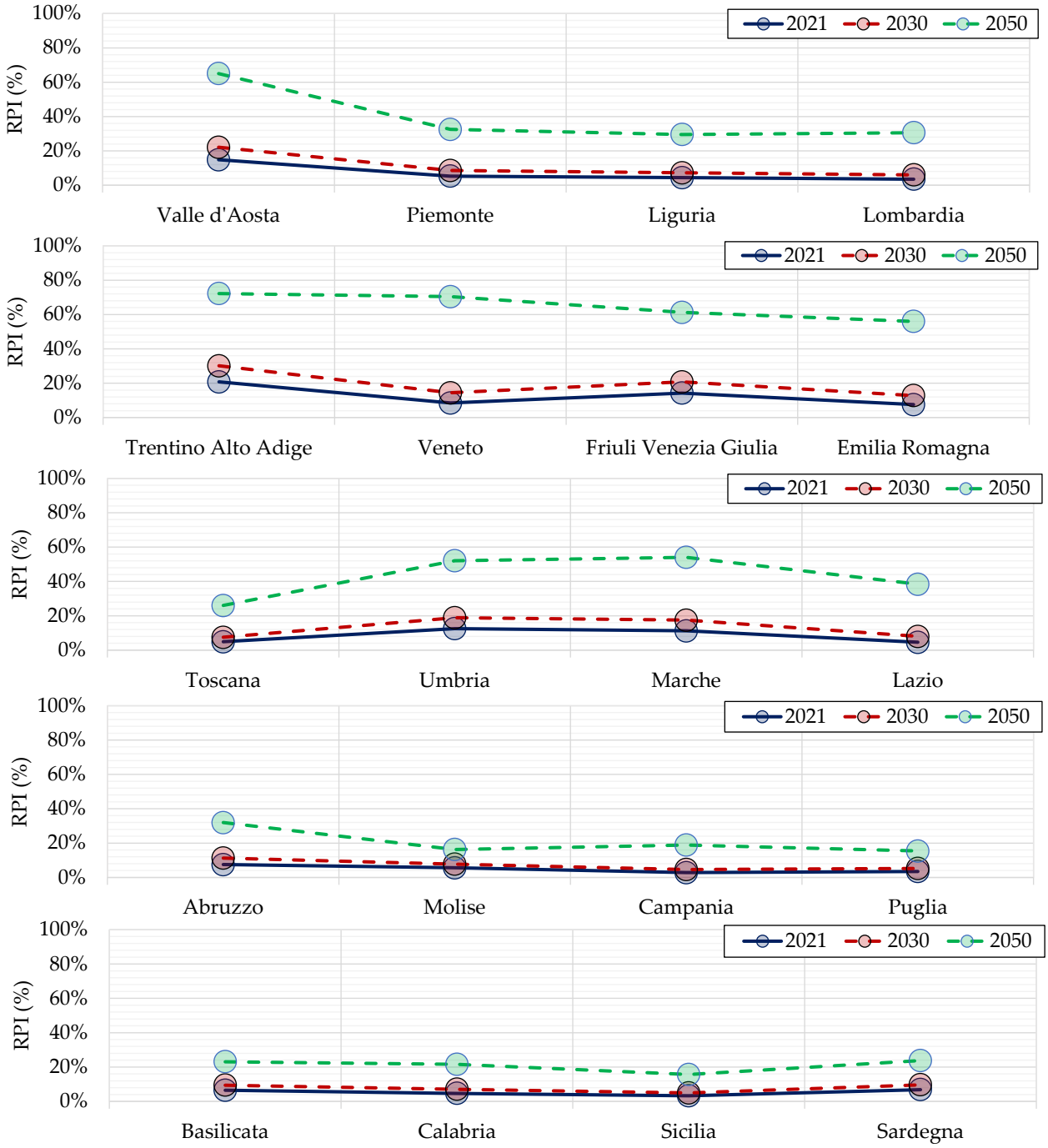


**Figure 10.** Regional Potential Index (RPI) calculated for each region and different years: 2021 (current situation), 2030 (red lines), and 2050 (green lines).

According to this premise, climate change can negatively influence the assessed producibility of photovoltaic panels through various environmental factors; however, many of these influences are still being researched, and it was not possible to forecast or include the real influence of climate change on our analysis. The study of its effects on the producibility of photovoltaic panels could be investigated in a medium-to-long-term study.

## 4. Conclusions

The International Energy Agency (IEA) has indicated solar photovoltaic systems as a key player in the country's energy mix. Italy has set a target of achieving 52 GW of photovoltaic capacity by 2030, which is two and a half times the capacity recorded in 2020. Therefore, solar photovoltaic energy could be crucial for meeting increasing energy needs while reducing greenhouse gas emissions, both in Europe and Italy. Despite the potential and convenience of solar photovoltaic energy, there are several challenges associated with solar photovoltaic energy, such as the intermittent nature of the source, the significant land use required for its implementation, and the high levels of bureaucracy and regulatory uncertainties. Nevertheless, photovoltaic systems play a key role in national energy policies, with new decrees being issued to reduce the bureaucracy and promote new installations of photovoltaic systems on the roofs of existing buildings.

In this framework, this study aims to evaluate the photovoltaic potential and energy production in the national context, without consuming additional land, by focusing only on the roof surface area of existing buildings. The study aims to answer three key points (KP) to assess the potential and critical issues associated with the implementation of national policies.

The study found that the roof surfaces of existing buildings offer a potential area of around 450 $km^2$, with considerable growth potential in several regions across Italy (KP1). Theoretically, the installable power on the roof surfaces could exceed 72 GW, enabling the production of over 79,000 GWh of energy (KP2). When compared to national objectives, namely the installation of 52 GW of new photovoltaic capacity by 2030, these objectives may potentially be achievable solely through the utilization of the roof surfaces of existing buildings, without the need for additional land use (KP3). However, the most probable scenarios have shown that it could be possible to reach only around 6 GW of photovoltaic power by 2030 overall, i.e., 11.5% of the national goal (KP2), indicating the need for a region-specific incentive system tailored to the real potential of each national zone (in terms of available surface area).

Moreover, the energy production in the moderate scenarios could only meet around 10% of the electricity needs of residential buildings, with an estimated production of around 6200 GWh at the national level (KP2-KP3). By 2050, photovoltaic production could potentially cover more than 38% of the energy needs but would still fall short of national and European targets. In the most promising scenarios, it could be possible to cover almost 50% of the electricity consumption by 2050 with long-term energy incentives (KP2-KP3). The use of the roof surface of existing buildings can help to reduce the land use required for this type of application; however, it is not enough to achieve the ambitious energy targets by 2030. Nevertheless, some regions of Italy, such as Veneto, Emilia Romagna, and Lombardia, could come close to meeting national targets but only by 2050, even in a moderate scenario, indicating the need to develop different forms of energy incentives in the national context. Although this study has considered the more conservative scenarios, it did not take into account the effects of climatic change, which can negatively influence the assessed energy production of photovoltaic panels due to various environmental factors. To evaluate the influence of climatic change on the present forecasting analysis a medium-to-long-term study should be carried out.

Finally, based on these results, a new index, namely the regional potential index, was also defined as the ratio between the photovoltaic power installed and the theoretical maximum that could be installed based on the calculated optimal roof surface areas. This index can be used to evaluate the photovoltaic potential for each region and it could be useful as support for the development of specific incentives based on the real availability of roof surface areas of the regions.

**Author Contributions:** Conceptualization, D.P.; methodology, D.P.; software, D.P.; validation, D.P.; formal analysis, D.P.; investigation, D.P.; resources, D.P. and N.C; data curation, D.P.; writing—original draft preparation, D.P.; writing—review and editing, D.P.; visualization, D.P.; supervision, D.P. and N.C. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviation

| | |
|---|---|
| BU | Building units |
| C | Centre |
| DE | Difference between energy consumption and energy produced by photovoltaic panels |
| DR | Development rate |
| EC | Energy consumption |
| GR | Growth rate |
| I | Islands |
| KP | Key point |
| MFH | Multi-family house |
| NE | Northeast |
| NW | Northwest |
| P | Power |
| PhV | Photovoltaics |
| RPI | Regional potential index |
| S | South |
| SFH | Single-family house |

## Appendix A

**Table A1.** Building distribution (absolute values): breakdown by geographical area of Italy, number of building floors, and building type (single-family house—SFH and multi-family house—MFH).

| Zones | SFH | | MFH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 Floor | 2 Floors | | | 3 Floors | | | ≥4 Floors | | | |
| | n. 1 | n. 1 | n. 2 | n. 3–4 | n. 2 | n. 3–4 | n. 5–8 | n. 3–4 | n. 5–8 | n. 9–15 | n. ≥16 |
| Piemonte | 2,083,389 | 4,458,357 | 1,232,233 | 290,666 | 1,506,062 | 407,623 | 646,827 | 728,390 | 71,870 | 324,261 | 219,559 |
| Valle d'Aosta | 82,127 | 475,443 | 51,209 | 5690 | 147,405 | 24,361 | 39,776 | 55,212 | 4420 | 25,045 | 21,953 |
| Liguria | 3135 | 15,452 | 0 | 0 | 11,400 | 2050 | 2670 | 5125 | 297 | 1056 | 701 |
| Lombardia | 29,963 | 86,319 | 25,020 | 2780 | 34,336 | 10,097 | 19,193 | 22,462 | 2133 | 13,698 | 14,919 |
| Trentino Alto Adige | 135,547 | 519,959 | 170,355 | 118,771 | 208,211 | 61,571 | 106,533 | 35,156 | 13,047 | 57,984 | 44,248 |
| Veneto | 10,893 | 65,281 | 0 | 0 | 47,781 | 9288 | 17,109 | 23,219 | 1901 | 5617 | 3110 |
| Friuli Venezia Giulia | 93,862 | 478,762 | 118,525 | 69,672 | 144,863 | 32,775 | 47,210 | 12,265 | 12,832 | 23,705 | 10,824 |
| Emilia Romagna | 35,916 | 156,712 | 0 | 0 | 57,459 | 6240 | 12,549 | 15,600 | 1394 | 8393 | 4217 |
| Toscana | 60,500 | 310,998 | 93,821 | 28,403 | 114,671 | 33,069 | 60,398 | 54,270 | 6711 | 30,295 | 15,597 |
| Umbria | 79,859 | 279,145 | 79,127 | 42,309 | 96,711 | 29,111 | 48,438 | 30,468 | 5382 | 21,313 | 11,218 |
| Marche | 15,817 | 86,717 | 16,748 | 1861 | 37,430 | 7007 | 8708 | 15,656 | 968 | 3661 | 1946 |
| Lazio | 21,253 | 122,228 | 21,674 | 2408 | 63,507 | 12,725 | 20,476 | 29,404 | 2275 | 8801 | 3501 |
| Abruzzo | 153,357 | 220,709 | 81,749 | 63,115 | 99,916 | 31,844 | 41,628 | 16,496 | 19,242 | 33,933 | 27,743 |
| Molise | 44,813 | 153,658 | 16,368 | 1819 | 60,139 | 11,102 | 15,242 | 25,937 | 1694 | 6716 | 3775 |
| Campania | 13,351 | 48,913 | 0 | 0 | 17,693 | 2383 | 2806 | 5957 | 312 | 1412 | 977 |
| Puglia | 159,125 | 270,142 | 97,531 | 98,438 | 119,205 | 28,335 | 26,714 | 0 | 32,444 | 22,885 | 18,287 |
| Basilicata | 427,892 | 160,169 | 76,919 | 81,820 | 94,012 | 0 | 0 | 0 | 39,413 | 19,612 | 13,488 |
| Calabria | 39,307 | 53,922 | 14,972 | 1664 | 19,950 | 4978 | 6364 | 10,781 | 707 | 2493 | 1133 |
| Sicilia | 138,784 | 217,662 | 48,505 | 5389 | 80,147 | 19,152 | 25,177 | 42,491 | 2797 | 9583 | 4677 |
| Sardegna | 400,175 | 477,253 | 56,842 | 6316 | 226,965 | 39,849 | 48,536 | 93,306 | 5393 | 21,251 | 13,485 |

**Table A2.** Building units distribution (absolute values): breakdown by geographical area of Italy, number of building floors, and building type (single-family house—SFH and multi-family house—MFH).

| Zones | SFH | MFH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 Floor | 2 Floors | | 3 Floors | | | ≥4 Floors | | | |
| | n. 1 | n. 1 | n. 2 | n. 3–4 | n. 2 | n. 3–4 | n. 5–8 | n. 3–4 | n. 5–8 | n. 9–15 | n. ≥16 |
| Piemonte | 82,127 | 475,443 | 102,418 | 22,760 | 294,810 | 97,442 | 238,658 | 220,846 | 26,518 | 300,540 | 526,872 |
| Valle d'Aosta | 3135 | 15,452 | 0 | 0 | 22,800 | 8200 | 16,022 | 20,500 | 1780 | 12,672 | 16,824 |
| Liguria | 29,963 | 86,319 | 50,040 | 11,120 | 68,672 | 40,387 | 115,160 | 89,849 | 12,796 | 164,376 | 358,056 |
| Lombardia | 135,547 | 519,959 | 340,709 | 475,085 | 416,423 | 246,283 | 639,197 | 140,623 | 78,283 | 695,808 | 1,061,952 |
| Trentino Alto Adige | 10,893 | 65,281 | 0 | 0 | 95,562 | 37,151 | 102,654 | 92,877 | 11,406 | 67,404 | 74,640 |
| Veneto | 93,862 | 478,762 | 237,049 | 278,690 | 289,727 | 131,101 | 283,259 | 49,062 | 76,993 | 284,460 | 259,776 |
| Friuli Venezia Giulia | 35,916 | 156,712 | 0 | 0 | 114,918 | 24,960 | 75,292 | 62,400 | 8366 | 100,716 | 101,208 |
| Emilia Romagna | 60,500 | 310,998 | 187,643 | 113,610 | 229,341 | 132,277 | 362,389 | 217,081 | 40,265 | 363,540 | 374,328 |
| Toscana | 79,859 | 279,145 | 158,254 | 169,236 | 193,422 | 116,442 | 290,628 | 121,870 | 32,292 | 255,756 | 269,232 |
| Umbria | 15,817 | 86,717 | 33,496 | 7444 | 74,860 | 28,027 | 52,245 | 62,625 | 5805 | 43,932 | 46,704 |
| Marche | 21,253 | 122,228 | 43,348 | 9633 | 127,014 | 50,899 | 122,855 | 117,616 | 13,651 | 105,612 | 84,024 |
| Lazio | 153,357 | 220,709 | 163,499 | 252,459 | 199,832 | 127,377 | 249,766 | 65,984 | 115,454 | 407,196 | 665,832 |
| Abruzzo | 44,813 | 153,658 | 32,737 | 7275 | 120,277 | 44,409 | 91,454 | 103,748 | 10,162 | 80,592 | 90,600 |
| Molise | 13,351 | 48,913 | 0 | 0 | 35,386 | 9531 | 16,837 | 23,829 | 1871 | 16,944 | 23,448 |
| Campania | 159,125 | 270,142 | 195,062 | 393,751 | 238,410 | 113,341 | 160,285 | 0 | 194,663 | 274,620 | 438,888 |
| Puglia | 427,892 | 160,169 | 153,838 | 327,280 | 188,024 | 0 | 0 | 0 | 236,478 | 235,344 | 323,712 |
| Basilicata | 39,307 | 53,922 | 29,945 | 6654 | 39,899 | 19,911 | 38,183 | 43,123 | 4243 | 29,916 | 27,192 |
| Calabria | 138,784 | 217,662 | 97,009 | 21,558 | 160,295 | 76,608 | 151,060 | 169,962 | 16,784 | 114,996 | 112,248 |
| Sicilia | 400,175 | 477,253 | 113,684 | 25,263 | 453,930 | 159,394 | 291,217 | 373,223 | 32,357 | 255,012 | 323,640 |
| Sardegna | 137,713 | 216,538 | 69,622 | 15,472 | 104,636 | 41,697 | 85,369 | 88,771 | 9485 | 81,696 | 90,240 |

**Table A3.** Total net surface area distribution (absolute values in $km^2$) of building units (BU): breakdown by geographical area of Italy (Northwest, Northeast, Centre, South, and Islands) and building type (single-family house—SFH and multi-family house—MFH).

| Building Type | Area | Net Surface Distribution of the Building Units ($km^2$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ≤29 | 30–39 | 40–49 | 50–59 | 60–79 | 80–99 | 100–119 | 120–149 | ≥150 |
| SFH | Northwest | 0.00 | 0.22 | 1.15 | 2.84 | 13.25 | 21.72 | 18.33 | 17.45 | 27.77 |
| | Northeast | 0.00 | 0.12 | 0.69 | 1.74 | 9.36 | 18.25 | 19.79 | 20.40 | 35.66 |
| | Centre | 0.00 | 0.15 | 0.76 | 1.90 | 9.69 | 17.41 | 16.57 | 14.84 | 21.76 |
| | South | 0.00 | 0.31 | 1.34 | 3.04 | 15.87 | 37.16 | 38.98 | 36.09 | 47.29 |
| | Islands | 0.00 | 0.21 | 0.96 | 2.14 | 10.63 | 23.48 | 28.72 | 27.59 | 33.67 |
| MFH (2 floors) | Northwest | 0.03 | 0.72 | 2.41 | 4.31 | 15.62 | 22.70 | 16.62 | 13.74 | 18.71 |
| | Northeast | 0.01 | 0.18 | 0.68 | 1.26 | 5.50 | 9.04 | 8.36 | 7.76 | 12.50 |
| | Centre | 0.01 | 0.31 | 0.96 | 1.74 | 6.75 | 9.18 | 7.08 | 5.52 | 7.30 |
| | South | 0.02 | 0.41 | 1.09 | 1.80 | 7.35 | 13.79 | 11.71 | 8.78 | 10.05 |
| | Islands | 0.00 | 0.06 | 0.17 | 0.28 | 1.08 | 1.96 | 2.05 | 1.65 | 1.77 |
| MFH (3 floors) | Northwest | 0.03 | 0.90 | 2.99 | 5.36 | 19.51 | 27.80 | 20.29 | 16.83 | 23.22 |
| | Northeast | 0.01 | 0.25 | 0.91 | 1.67 | 7.15 | 11.43 | 10.39 | 9.33 | 14.56 |
| | Centre | 0.01 | 0.33 | 1.01 | 1.84 | 7.27 | 10.22 | 8.03 | 6.26 | 8.22 |
| | South | 0.01 | 0.24 | 0.64 | 1.06 | 4.29 | 7.81 | 6.81 | 5.19 | 6.00 |
| | Islands | 0.01 | 0.24 | 0.68 | 1.09 | 4.23 | 7.71 | 8.10 | 6.32 | 6.66 |
| MFH (≥4 floors) | Northwest | 0.03 | 0.73 | 2.43 | 4.36 | 15.90 | 22.46 | 16.33 | 13.52 | 18.69 |
| | Northeast | 0.01 | 0.17 | 0.60 | 1.11 | 4.71 | 7.45 | 6.67 | 5.91 | 9.10 |
| | Centre | 0.01 | 0.30 | 0.94 | 1.70 | 6.56 | 8.97 | 6.96 | 5.41 | 7.10 |
| | South | 0.01 | 0.26 | 0.68 | 1.13 | 4.63 | 8.71 | 7.52 | 5.76 | 6.62 |
| | Islands | 0.01 | 0.16 | 0.44 | 0.70 | 2.74 | 5.00 | 5.25 | 4.10 | 4.33 |

**Table A4.** Energy production obtained from forecasting analysis: scenario n. 1 ($GR_{PhV-1}$).

| Years | National Regions | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| 2016 | 210 | 9 | 27 | 387 | 86 | 399 | 127 | 281 | 153 | 68 | 104 | 206 | 82 | 19 | 131 | 193 | 35 | 118 | 252 | 170 |
| 2017 | 231 | 10 | 31 | 435 | 100 | 446 | 136 | 321 | 173 | 80 | 123 | 241 | 105 | 22 | 150 | 244 | 39 | 138 | 294 | 195 |
| 2018 | 222 | 10 | 31 | 440 | 97 | 457 | 138 | 312 | 164 | 74 | 114 | 232 | 99 | 20 | 144 | 229 | 36 | 128 | 281 | 177 |
| 2019 | 246 | 11 | 31 | 484 | 99 | 477 | 140 | 343 | 178 | 81 | 124 | 251 | 107 | 22 | 157 | 245 | 38 | 140 | 300 | 194 |
| 2020 | 237 | 11 | 34 | 500 | 95 | 519 | 150 | 344 | 176 | 81 | 121 | 269 | 103 | 22 | 162 | 241 | 38 | 137 | 304 | 191 |
| 2021 | 247 | 10 | 36 | 533 | 92 | 559 | 152 | 353 | 182 | 76 | 117 | 262 | 97 | 20 | 161 | 227 | 35 | 133 | 291 | 180 |
| 2022 | 248 | 11 | 34 | 505 | 99 | 518 | 148 | 351 | 182 | 80 | 124 | 264 | 105 | 22 | 161 | 246 | 39 | 140 | 307 | 193 |
| 2023 | 263 | 10 | 38 | 578 | 101 | 573 | 159 | 374 | 186 | 78 | 120 | 264 | 100 | 20 | 161 | 228 | 35 | 127 | 275 | 173 |
| 2024 | 280 | 11 | 40 | 627 | 105 | 622 | 167 | 402 | 198 | 81 | 127 | 285 | 107 | 21 | 172 | 244 | 37 | 133 | 293 | 181 |
| 2025 | 299 | 12 | 43 | 681 | 109 | 675 | 176 | 431 | 210 | 84 | 134 | 308 | 114 | 21 | 184 | 260 | 39 | 141 | 313 | 189 |
| 2026 | 319 | 12 | 47 | 740 | 113 | 733 | 185 | 463 | 223 | 87 | 142 | 332 | 121 | 22 | 196 | 278 | 40 | 148 | 333 | 198 |
| 2027 | 340 | 13 | 50 | 803 | 117 | 795 | 195 | 498 | 237 | 91 | 150 | 358 | 129 | 23 | 209 | 297 | 42 | 156 | 355 | 207 |
| 2028 | 362 | 14 | 53 | 872 | 122 | 863 | 206 | 535 | 252 | 95 | 158 | 387 | 137 | 24 | 223 | 318 | 44 | 164 | 378 | 216 |
| 2029 | 386 | 14 | 57 | 947 | 127 | 936 | 217 | 574 | 268 | 98 | 167 | 417 | 146 | 25 | 238 | 340 | 46 | 173 | 403 | 226 |
| 2030 | 411 | 15 | 61 | 1029 | 132 | 1016 | 228 | 617 | 285 | 102 | 177 | 450 | 155 | 26 | 254 | 363 | 48 | 183 | 430 | 236 |
| 2031 | 439 | 16 | 66 | 1117 | 137 | 1103 | 240 | 663 | 303 | 106 | 187 | 486 | 165 | 27 | 270 | 388 | 50 | 192 | 458 | 247 |
| 2032 | 468 | 17 | 71 | 1213 | 143 | 1197 | 253 | 712 | 322 | 111 | 198 | 524 | 176 | 28 | 289 | 414 | 53 | 203 | 488 | 258 |
| 2033 | 498 | 18 | 76 | 1317 | 148 | 1299 | 266 | 765 | 343 | 115 | 209 | 566 | 187 | 30 | 308 | 443 | 55 | 214 | 520 | 270 |
| 2034 | 531 | 19 | 81 | 1430 | 154 | 1409 | 281 | 821 | 364 | 120 | 221 | 611 | 199 | 31 | 328 | 473 | 58 | 225 | 554 | 282 |
| 2035 | 566 | 20 | 87 | 1553 | 160 | 1529 | 295 | 882 | 387 | 125 | 233 | 659 | 212 | 32 | 350 | 506 | 60 | 237 | 590 | 295 |
| 2036 | 604 | 21 | 93 | 1686 | 167 | 1660 | 311 | 948 | 412 | 130 | 247 | 711 | 226 | 34 | 374 | 540 | 63 | 250 | 629 | 308 |
| 2037 | 644 | 22 | 100 | 1831 | 173 | 1801 | 328 | 1018 | 438 | 135 | 261 | 767 | 240 | 35 | 398 | 578 | 66 | 263 | 670 | 322 |
| 2038 | 686 | 23 | 107 | 1988 | 180 | 1954 | 345 | 1094 | 465 | 140 | 276 | 828 | 256 | 36 | 425 | 617 | 69 | 277 | 714 | 337 |
| 2039 | 731 | 24 | 115 | 2159 | 188 | 2121 | 363 | 1175 | 494 | 146 | 291 | 893 | 272 | 38 | 453 | 660 | 72 | 292 | 761 | 352 |
| 2040 | 779 | 26 | 123 | 2345 | 195 | 2301 | 383 | 1262 | 526 | 152 | 308 | 964 | 290 | 39 | 484 | 705 | 75 | 308 | 811 | 368 |
| 2041 | 831 | 27 | 132 | 2546 | 203 | 2497 | 403 | 1356 | 559 | 158 | 326 | 1040 | 308 | 41 | 516 | 753 | 79 | 324 | 864 | 384 |
| 2042 | 886 | 29 | 142 | 2765 | 211 | 2710 | 424 | 1456 | 594 | 164 | 344 | 1122 | 328 | 43 | 550 | 805 | 82 | 342 | 921 | 402 |
| 2043 | 944 | 30 | 152 | 3002 | 219 | 2941 | 447 | 1564 | 631 | 171 | 364 | 1211 | 349 | 45 | 587 | 860 | 86 | 360 | 981 | 420 |
| 2044 | 1006 | 32 | 163 | 3260 | 228 | 3192 | 471 | 1680 | 671 | 178 | 385 | 1307 | 372 | 46 | 626 | 919 | 90 | 379 | 1046 | 439 |
| 2045 | 1073 | 33 | 175 | 3540 | 237 | 3463 | 496 | 1805 | 714 | 185 | 407 | 1410 | 396 | 48 | 668 | 982 | 94 | 400 | 1115 | 459 |
| 2046 | 1144 | 35 | 188 | 3844 | 246 | 3758 | 522 | 1939 | 759 | 192 | 430 | 1522 | 421 | 50 | 713 | 1050 | 98 | 421 | 1188 | 480 |
| 2047 | 1219 | 37 | 201 | 4174 | 256 | 4079 | 550 | 2083 | 806 | 200 | 454 | 1642 | 448 | 52 | 760 | 1122 | 103 | 444 | 1266 | 502 |
| 2048 | 1300 | 39 | 216 | 4532 | 266 | 4426 | 579 | 2237 | 857 | 208 | 480 | 1772 | 477 | 55 | 811 | 1199 | 108 | 467 | 1349 | 524 |
| 2049 | 1385 | 41 | 231 | 4922 | 277 | 4803 | 610 | 2403 | 911 | 216 | 508 | 1912 | 508 | 57 | 865 | 1281 | 112 | 492 | 1437 | 548 |
| 2050 | 1477 | 43 | 248 | 5344 | 288 | 5212 | 642 | 2582 | 969 | 225 | 537 | 2063 | 540 | 59 | 923 | 1369 | 118 | 519 | 1531 | 573 |

1—Piemonte, 2—Valle d'Aosta, 3—Liguria, 4—Lombadia, 5—Trentino Alto Adige, 6—Veneto, 7—Friuli Venezia Giulia, 8—Emilia Romagna, 9—Toscana, 10—Umbria, 11—Marche, 12—Lazio, 13—Abruzzo, 14—Molise, 15—Campania, 16—Puglia, 17—Basilicata, 18—Calabria, 19—Sicilia, and 20—Sardegna.

**Table A5.** Energy production obtained from forecasting analysis: scenario n. 2 ($GR_{PhV-2}$).

| Years | National Regions | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| 2016 | 210 | 9 | 27 | 387 | 86 | 399 | 127 | 281 | 153 | 68 | 104 | 206 | 82 | 19 | 131 | 193 | 35 | 118 | 252 | 170 |
| 2017 | 231 | 10 | 31 | 435 | 100 | 446 | 136 | 321 | 173 | 80 | 123 | 241 | 105 | 22 | 150 | 244 | 39 | 138 | 294 | 195 |
| 2018 | 222 | 10 | 31 | 440 | 97 | 457 | 138 | 312 | 164 | 74 | 114 | 232 | 99 | 20 | 144 | 229 | 36 | 128 | 281 | 177 |
| 2019 | 246 | 11 | 31 | 484 | 99 | 477 | 140 | 343 | 178 | 81 | 124 | 251 | 107 | 22 | 157 | 245 | 38 | 140 | 300 | 194 |
| 2020 | 237 | 11 | 34 | 500 | 95 | 519 | 150 | 344 | 176 | 81 | 121 | 269 | 103 | 22 | 162 | 241 | 38 | 137 | 304 | 191 |
| 2021 | 247 | 10 | 36 | 533 | 92 | 559 | 152 | 353 | 182 | 76 | 117 | 262 | 97 | 20 | 161 | 227 | 35 | 133 | 291 | 180 |
| 2022 | 249 | 11 | 34 | 504 | 99 | 517 | 148 | 351 | 183 | 81 | 124 | 264 | 104 | 22 | 162 | 243 | 39 | 140 | 305 | 193 |
| 2023 | 264 | 11 | 38 | 576 | 101 | 571 | 160 | 376 | 186 | 80 | 120 | 266 | 98 | 20 | 163 | 222 | 35 | 128 | 272 | 173 |
| 2024 | 283 | 11 | 41 | 625 | 106 | 618 | 168 | 404 | 198 | 84 | 127 | 287 | 103 | 20 | 175 | 235 | 37 | 135 | 288 | 181 |
| 2025 | 302 | 12 | 44 | 677 | 111 | 669 | 178 | 435 | 211 | 88 | 134 | 311 | 109 | 21 | 188 | 247 | 39 | 143 | 305 | 189 |
| 2026 | 323 | 12 | 47 | 735 | 116 | 724 | 188 | 469 | 224 | 93 | 142 | 336 | 115 | 22 | 202 | 261 | 40 | 151 | 324 | 198 |
| 2027 | 345 | 13 | 50 | 797 | 121 | 784 | 198 | 505 | 239 | 97 | 150 | 364 | 121 | 23 | 216 | 275 | 42 | 159 | 343 | 207 |
| 2028 | 369 | 14 | 54 | 864 | 126 | 848 | 209 | 543 | 254 | 102 | 159 | 393 | 127 | 24 | 232 | 291 | 44 | 169 | 363 | 217 |

**Table A5.** *Cont.*

| Years | National Regions | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| 2029 | 394 | 15 | 58 | 937 | 132 | 918 | 221 | 585 | 270 | 108 | 168 | 425 | 134 | 25 | 249 | 307 | 46 | 178 | 385 | 227 |
| 2030 | 421 | 15 | 62 | 1016 | 138 | 994 | 233 | 630 | 288 | 113 | 178 | 460 | 141 | 25 | 267 | 323 | 48 | 189 | 408 | 237 |
| 2031 | 450 | 16 | 66 | 1101 | 144 | 1076 | 246 | 678 | 306 | 119 | 189 | 498 | 149 | 26 | 287 | 341 | 50 | 199 | 432 | 248 |
| 2032 | 481 | 17 | 71 | 1194 | 150 | 1165 | 259 | 730 | 326 | 125 | 199 | 538 | 157 | 27 | 308 | 360 | 53 | 211 | 457 | 259 |
| 2033 | 514 | 18 | 76 | 1295 | 157 | 1261 | 274 | 786 | 347 | 132 | 211 | 582 | 165 | 29 | 330 | 380 | 55 | 223 | 485 | 271 |
| 2034 | 549 | 19 | 82 | 1404 | 164 | 1365 | 289 | 846 | 369 | 139 | 223 | 630 | 174 | 30 | 355 | 401 | 58 | 236 | 513 | 284 |
| 2035 | 587 | 20 | 88 | 1522 | 171 | 1478 | 305 | 911 | 393 | 146 | 236 | 681 | 183 | 31 | 380 | 423 | 60 | 249 | 544 | 297 |
| 2036 | 627 | 21 | 94 | 1651 | 179 | 1600 | 322 | 981 | 418 | 154 | 250 | 737 | 193 | 32 | 408 | 446 | 63 | 263 | 576 | 311 |
| 2037 | 670 | 22 | 101 | 1790 | 187 | 1732 | 340 | 1056 | 445 | 162 | 264 | 797 | 204 | 33 | 438 | 471 | 66 | 279 | 610 | 325 |
| 2038 | 716 | 24 | 109 | 1941 | 195 | 1875 | 359 | 1137 | 473 | 170 | 280 | 862 | 215 | 34 | 470 | 497 | 69 | 295 | 647 | 340 |
| 2039 | 766 | 25 | 117 | 2104 | 204 | 2030 | 379 | 1224 | 504 | 179 | 296 | 933 | 226 | 36 | 504 | 524 | 72 | 311 | 685 | 355 |
| 2040 | 818 | 26 | 125 | 2282 | 213 | 2197 | 400 | 1318 | 536 | 188 | 313 | 1009 | 238 | 37 | 541 | 553 | 75 | 329 | 726 | 372 |
| 2041 | 874 | 28 | 134 | 2474 | 223 | 2379 | 422 | 1419 | 570 | 198 | 331 | 1091 | 251 | 38 | 581 | 583 | 79 | 348 | 769 | 389 |
| 2042 | 935 | 29 | 144 | 2683 | 233 | 2575 | 445 | 1528 | 607 | 208 | 351 | 1180 | 264 | 40 | 623 | 615 | 83 | 368 | 815 | 407 |
| 2043 | 999 | 31 | 155 | 2909 | 243 | 2788 | 470 | 1645 | 646 | 219 | 371 | 1276 | 278 | 41 | 669 | 649 | 86 | 389 | 863 | 425 |
| 2044 | 1067 | 33 | 166 | 3155 | 254 | 3018 | 496 | 1771 | 687 | 230 | 393 | 1381 | 293 | 43 | 718 | 685 | 90 | 412 | 914 | 445 |
| 2045 | 1141 | 35 | 178 | 3421 | 265 | 3267 | 524 | 1906 | 731 | 242 | 415 | 1493 | 309 | 45 | 770 | 723 | 94 | 435 | 969 | 465 |
| 2046 | 1219 | 36 | 191 | 3709 | 277 | 3536 | 553 | 2052 | 778 | 255 | 439 | 1615 | 325 | 46 | 826 | 762 | 99 | 460 | 1026 | 487 |
| 2047 | 1303 | 38 | 205 | 4022 | 290 | 3828 | 584 | 2210 | 828 | 268 | 465 | 1747 | 343 | 48 | 887 | 804 | 103 | 487 | 1087 | 509 |
| 2048 | 1392 | 41 | 220 | 4361 | 303 | 4144 | 616 | 2379 | 881 | 282 | 492 | 1890 | 361 | 50 | 951 | 849 | 108 | 515 | 1152 | 533 |
| 2049 | 1488 | 43 | 236 | 4729 | 316 | 4486 | 650 | 2561 | 938 | 297 | 521 | 2044 | 380 | 52 | 1021 | 895 | 113 | 544 | 1220 | 557 |
| 2050 | 1590 | 45 | 253 | 5128 | 330 | 4857 | 686 | 2758 | 998 | 312 | 551 | 2211 | 401 | 54 | 1095 | 945 | 118 | 575 | 1292 | 583 |

1—Piemonte, 2—Valle d'Aosta, 3—Liguria, 4—Lombadia, 5—Trentino Alto Adige, 6—Veneto, 7—Friuli Venezia Giulia, 8—Emilia Romagna, 9—Toscana, 10—Umbria, 11—Marche, 12—Lazio, 13—Abruzzo, 14—Molise, 15—Campania, 16—Puglia, 17—Basilicata, 18—Calabria, 19—Sicilia, and 20—Sardegna.

**Table A6.** Energy production obtained from forecasting analysis: scenario n. 3 ($GR_{PhV\text{-}3}$).

| Years | National Regions | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| 2016 | 210 | 9 | 27 | 387 | 86 | 399 | 127 | 281 | 153 | 68 | 104 | 206 | 82 | 19 | 131 | 193 | 35 | 118 | 252 | 170 |
| 2017 | 231 | 10 | 31 | 435 | 100 | 446 | 136 | 321 | 173 | 80 | 123 | 241 | 105 | 22 | 150 | 244 | 39 | 138 | 294 | 195 |
| 2018 | 222 | 10 | 31 | 440 | 97 | 457 | 138 | 312 | 164 | 74 | 114 | 232 | 99 | 20 | 144 | 229 | 36 | 128 | 281 | 177 |
| 2019 | 246 | 11 | 31 | 484 | 99 | 477 | 140 | 343 | 178 | 81 | 124 | 251 | 107 | 22 | 157 | 245 | 38 | 140 | 300 | 194 |
| 2020 | 237 | 11 | 34 | 500 | 95 | 519 | 150 | 344 | 176 | 81 | 121 | 269 | 103 | 22 | 162 | 241 | 38 | 137 | 304 | 191 |
| 2021 | 247 | 10 | 36 | 533 | 92 | 559 | 152 | 353 | 182 | 76 | 117 | 262 | 97 | 20 | 161 | 227 | 35 | 133 | 291 | 180 |
| 2022 | 250 | 11 | 34 | 508 | 100 | 522 | 149 | 353 | 184 | 81 | 125 | 266 | 108 | 22 | 163 | 253 | 39 | 141 | 311 | 195 |
| 2023 | 267 | 11 | 38 | 586 | 103 | 582 | 160 | 379 | 189 | 81 | 122 | 268 | 106 | 20 | 164 | 240 | 37 | 129 | 283 | 176 |
| 2024 | 287 | 11 | 41 | 641 | 109 | 636 | 170 | 409 | 203 | 86 | 130 | 292 | 115 | 21 | 177 | 264 | 39 | 137 | 306 | 186 |
| 2025 | 309 | 12 | 45 | 700 | 115 | 696 | 179 | 443 | 217 | 91 | 138 | 317 | 126 | 22 | 190 | 289 | 41 | 146 | 330 | 196 |
| 2026 | 332 | 13 | 48 | 766 | 121 | 761 | 190 | 479 | 233 | 97 | 147 | 345 | 137 | 24 | 205 | 317 | 44 | 155 | 356 | 207 |
| 2027 | 357 | 14 | 52 | 838 | 127 | 832 | 201 | 517 | 250 | 103 | 157 | 375 | 150 | 25 | 220 | 348 | 47 | 164 | 385 | 218 |
| 2028 | 383 | 15 | 56 | 916 | 134 | 910 | 213 | 559 | 268 | 109 | 167 | 407 | 164 | 26 | 237 | 382 | 50 | 175 | 416 | 230 |
| 2029 | 412 | 16 | 61 | 1001 | 141 | 995 | 225 | 605 | 287 | 116 | 178 | 443 | 179 | 28 | 255 | 419 | 53 | 186 | 449 | 243 |
| 2030 | 443 | 17 | 65 | 1095 | 149 | 1087 | 238 | 654 | 308 | 123 | 189 | 481 | 195 | 29 | 274 | 459 | 57 | 197 | 485 | 256 |
| 2031 | 476 | 18 | 71 | 1197 | 157 | 1189 | 252 | 707 | 330 | 130 | 201 | 523 | 213 | 31 | 295 | 504 | 60 | 210 | 524 | 270 |
| 2032 | 511 | 19 | 76 | 1309 | 165 | 1300 | 266 | 764 | 354 | 138 | 214 | 569 | 233 | 32 | 318 | 553 | 64 | 223 | 566 | 285 |
| 2033 | 550 | 20 | 82 | 1431 | 174 | 1421 | 282 | 826 | 379 | 147 | 228 | 619 | 254 | 34 | 342 | 606 | 68 | 237 | 611 | 301 |
| 2034 | 591 | 21 | 89 | 1565 | 183 | 1554 | 298 | 893 | 407 | 156 | 243 | 672 | 278 | 36 | 368 | 665 | 73 | 252 | 660 | 317 |
| 2035 | 635 | 23 | 96 | 1711 | 193 | 1699 | 315 | 966 | 436 | 165 | 259 | 731 | 303 | 38 | 396 | 729 | 77 | 267 | 712 | 335 |
| 2036 | 682 | 24 | 104 | 1871 | 203 | 1858 | 334 | 1044 | 467 | 176 | 276 | 795 | 331 | 40 | 426 | 800 | 82 | 284 | 769 | 353 |
| 2037 | 733 | 26 | 112 | 2046 | 214 | 2031 | 353 | 1129 | 501 | 186 | 294 | 864 | 362 | 42 | 458 | 877 | 87 | 302 | 831 | 373 |
| 2038 | 788 | 28 | 121 | 2237 | 226 | 2221 | 374 | 1220 | 537 | 198 | 313 | 939 | 395 | 44 | 493 | 962 | 93 | 321 | 898 | 393 |
| 2039 | 847 | 29 | 131 | 2446 | 238 | 2428 | 395 | 1319 | 576 | 210 | 333 | 1021 | 431 | 47 | 530 | 1056 | 99 | 341 | 969 | 415 |
| 2040 | 910 | 31 | 141 | 2675 | 251 | 2655 | 418 | 1426 | 617 | 223 | 355 | 1110 | 471 | 49 | 571 | 1158 | 105 | 362 | 1047 | 437 |

**Table A6.** *Cont.*

| Years | National Regions | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| 2041 | 978 | 33 | 152 | 2925 | 264 | 2903 | 442 | 1542 | 662 | 237 | 378 | 1206 | 514 | 52 | 614 | 1270 | 112 | 385 | 1131 | 462 |
| 2042 | 1051 | 36 | 165 | 3198 | 278 | 3174 | 468 | 1667 | 710 | 251 | 403 | 1312 | 561 | 55 | 661 | 1393 | 119 | 409 | 1221 | 487 |
| 2043 | 1130 | 38 | 178 | 3497 | 293 | 3470 | 495 | 1803 | 761 | 266 | 429 | 1426 | 613 | 57 | 711 | 1529 | 127 | 435 | 1319 | 514 |
| 2044 | 1214 | 40 | 192 | 3824 | 309 | 3794 | 524 | 1949 | 816 | 283 | 457 | 1550 | 669 | 61 | 765 | 1677 | 135 | 462 | 1424 | 542 |
| 2045 | 1305 | 43 | 207 | 4181 | 325 | 4149 | 554 | 2107 | 874 | 300 | 486 | 1685 | 731 | 64 | 824 | 1839 | 144 | 491 | 1538 | 572 |
| 2046 | 1403 | 46 | 224 | 4572 | 343 | 4536 | 587 | 2278 | 938 | 319 | 518 | 1832 | 798 | 67 | 886 | 2017 | 153 | 522 | 1661 | 603 |
| 2047 | 1508 | 49 | 242 | 4999 | 361 | 4960 | 621 | 2463 | 1005 | 338 | 552 | 1991 | 871 | 71 | 954 | 2213 | 163 | 555 | 1794 | 636 |
| 2048 | 1620 | 52 | 261 | 5466 | 380 | 5423 | 657 | 2663 | 1078 | 359 | 588 | 2165 | 952 | 75 | 1026 | 2428 | 173 | 589 | 1938 | 671 |
| 2049 | 1741 | 55 | 282 | 5977 | 401 | 5929 | 695 | 2879 | 1155 | 381 | 626 | 2353 | 1039 | 79 | 1104 | 2663 | 184 | 626 | 2093 | 708 |
| 2050 | 1871 | 59 | 304 | 6535 | 422 | 6483 | 735 | 3112 | 1239 | 404 | 666 | 2558 | 1135 | 83 | 1188 | 2921 | 196 | 666 | 2261 | 747 |

1—Piemonte, 2—Valle d'Aosta, 3—Liguria, 4—Lombadia, 5—Trentino Alto Adige, 6—Veneto, 7—Friuli Venezia Giulia, 8—Emilia Romagna, 9—Toscana, 10—Umbria, 11—Marche, 12—Lazio, 13—Abruzzo, 14—Molise, 15—Campania, 16—Puglia, 17—Basilicata, 18—Calabria, 19—Sicilia, and 20—Sardegna.

**Table A7.** Energy production obtained from forecasting analysis: scenario n. 4 ($GR_{PhV\text{-}4}$).

| Years | National Regions | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| 2016 | 210 | 9 | 27 | 387 | 86 | 399 | 127 | 281 | 153 | 68 | 104 | 206 | 82 | 19 | 131 | 193 | 35 | 118 | 252 | 170 |
| 2017 | 231 | 10 | 31 | 435 | 100 | 446 | 136 | 321 | 173 | 80 | 123 | 241 | 105 | 22 | 150 | 244 | 39 | 138 | 294 | 195 |
| 2018 | 222 | 10 | 31 | 440 | 97 | 457 | 138 | 312 | 164 | 74 | 114 | 232 | 99 | 20 | 144 | 229 | 36 | 128 | 281 | 177 |
| 2019 | 246 | 11 | 31 | 484 | 99 | 477 | 140 | 343 | 178 | 81 | 124 | 251 | 107 | 22 | 157 | 245 | 38 | 140 | 300 | 194 |
| 2020 | 237 | 11 | 34 | 500 | 95 | 519 | 150 | 344 | 176 | 81 | 121 | 269 | 103 | 22 | 162 | 241 | 38 | 137 | 304 | 191 |
| 2021 | 247 | 10 | 36 | 533 | 92 | 559 | 152 | 353 | 182 | 76 | 117 | 262 | 97 | 20 | 161 | 227 | 35 | 133 | 291 | 180 |
| 2022 | 246 | 11 | 34 | 501 | 97 | 513 | 148 | 349 | 181 | 79 | 123 | 262 | 102 | 21 | 160 | 238 | 38 | 139 | 302 | 192 |
| 2023 | 259 | 10 | 37 | 569 | 98 | 563 | 158 | 369 | 183 | 75 | 118 | 261 | 95 | 19 | 159 | 214 | 34 | 125 | 267 | 170 |
| 2024 | 274 | 11 | 40 | 614 | 101 | 606 | 165 | 395 | 193 | 77 | 124 | 280 | 98 | 20 | 168 | 221 | 35 | 131 | 280 | 176 |
| 2025 | 290 | 11 | 42 | 661 | 103 | 652 | 173 | 421 | 203 | 79 | 130 | 300 | 102 | 20 | 178 | 229 | 36 | 137 | 294 | 182 |
| 2026 | 306 | 12 | 45 | 713 | 106 | 701 | 182 | 450 | 214 | 81 | 136 | 322 | 105 | 21 | 189 | 237 | 37 | 143 | 309 | 189 |
| 2027 | 324 | 12 | 48 | 768 | 109 | 754 | 191 | 480 | 225 | 83 | 143 | 346 | 109 | 21 | 200 | 245 | 38 | 150 | 324 | 196 |
| 2028 | 342 | 13 | 51 | 828 | 112 | 811 | 200 | 513 | 237 | 85 | 150 | 371 | 113 | 22 | 211 | 254 | 38 | 157 | 341 | 203 |
| 2029 | 362 | 13 | 55 | 893 | 115 | 872 | 210 | 548 | 250 | 87 | 157 | 397 | 117 | 23 | 224 | 262 | 39 | 164 | 357 | 210 |
| 2030 | 383 | 14 | 58 | 962 | 118 | 938 | 220 | 585 | 264 | 89 | 165 | 426 | 121 | 23 | 237 | 272 | 40 | 172 | 375 | 218 |
| 2031 | 405 | 14 | 62 | 1037 | 121 | 1009 | 231 | 625 | 278 | 91 | 173 | 457 | 125 | 24 | 251 | 281 | 41 | 180 | 394 | 226 |
| 2032 | 428 | 15 | 66 | 1118 | 124 | 1085 | 242 | 667 | 293 | 93 | 181 | 490 | 130 | 24 | 266 | 291 | 43 | 188 | 413 | 234 |
| 2033 | 453 | 16 | 71 | 1205 | 128 | 1167 | 254 | 713 | 309 | 95 | 190 | 526 | 134 | 25 | 281 | 301 | 44 | 197 | 434 | 242 |
| 2034 | 479 | 16 | 75 | 1299 | 131 | 1256 | 266 | 761 | 325 | 98 | 199 | 564 | 139 | 26 | 298 | 311 | 45 | 206 | 456 | 251 |
| 2035 | 506 | 17 | 80 | 1400 | 135 | 1351 | 279 | 813 | 343 | 100 | 209 | 605 | 144 | 26 | 315 | 322 | 46 | 216 | 478 | 260 |
| 2036 | 535 | 18 | 86 | 1509 | 138 | 1453 | 293 | 868 | 361 | 102 | 219 | 649 | 149 | 27 | 334 | 333 | 47 | 226 | 502 | 269 |
| 2037 | 566 | 19 | 91 | 1626 | 142 | 1563 | 307 | 927 | 381 | 105 | 230 | 696 | 155 | 28 | 354 | 345 | 48 | 236 | 527 | 279 |
| 2038 | 599 | 19 | 97 | 1753 | 146 | 1681 | 322 | 990 | 401 | 107 | 241 | 746 | 160 | 29 | 374 | 357 | 49 | 247 | 553 | 289 |
| 2039 | 633 | 20 | 104 | 1889 | 149 | 1808 | 338 | 1057 | 423 | 110 | 253 | 800 | 166 | 29 | 396 | 369 | 51 | 259 | 581 | 299 |
| 2040 | 670 | 21 | 111 | 2036 | 153 | 1944 | 355 | 1129 | 446 | 113 | 265 | 858 | 172 | 30 | 420 | 382 | 52 | 271 | 609 | 310 |
| 2041 | 708 | 22 | 118 | 2195 | 158 | 2091 | 372 | 1205 | 470 | 115 | 278 | 921 | 178 | 31 | 444 | 396 | 53 | 284 | 640 | 321 |
| 2042 | 749 | 23 | 126 | 2366 | 162 | 2250 | 390 | 1287 | 495 | 118 | 291 | 987 | 184 | 32 | 470 | 409 | 55 | 297 | 671 | 333 |
| 2043 | 792 | 24 | 134 | 2550 | 166 | 2420 | 409 | 1374 | 522 | 121 | 306 | 1059 | 191 | 33 | 498 | 423 | 56 | 311 | 705 | 345 |
| 2044 | 837 | 25 | 143 | 2748 | 171 | 2602 | 429 | 1468 | 550 | 124 | 320 | 1136 | 197 | 34 | 527 | 438 | 57 | 325 | 740 | 357 |
| 2045 | 886 | 26 | 152 | 2962 | 175 | 2799 | 450 | 1567 | 579 | 127 | 336 | 1218 | 204 | 35 | 558 | 453 | 59 | 340 | 777 | 370 |
| 2046 | 937 | 27 | 162 | 3193 | 180 | 3011 | 472 | 1674 | 610 | 130 | 352 | 1306 | 212 | 35 | 591 | 469 | 60 | 356 | 815 | 383 |
| 2047 | 990 | 28 | 173 | 3441 | 185 | 3238 | 495 | 1787 | 643 | 133 | 370 | 1401 | 219 | 36 | 626 | 486 | 62 | 373 | 856 | 397 |
| 2048 | 1047 | 29 | 184 | 3709 | 190 | 3483 | 520 | 1909 | 678 | 136 | 388 | 1503 | 227 | 37 | 663 | 502 | 63 | 390 | 898 | 412 |
| 2049 | 1108 | 31 | 197 | 3998 | 195 | 3747 | 545 | 2038 | 715 | 139 | 407 | 1612 | 235 | 38 | 701 | 520 | 65 | 408 | 943 | 426 |
| 2050 | 1171 | 32 | 210 | 4309 | 200 | 4030 | 572 | 2177 | 753 | 143 | 426 | 1728 | 243 | 39 | 743 | 538 | 67 | 427 | 990 | 442 |

1—Piemonte, 2—Valle d'Aosta, 3—Liguria, 4—Lombadia, 5—Trentino Alto Adige, 6—Veneto, 7—Friuli Venezia Giulia, 8—Emilia Romagna, 9—Toscana, 10—Umbria, 11—Marche, 12—Lazio, 13—Abruzzo, 14—Molise, 15—Campania, 16—Puglia, 17—Basilicata, 18—Calabria, 19—Sicilia, and 20—Sardegna.

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