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# Diffusion of Solar PV Energy in Italy: Can Large-Scale PV Installations Trigger the Next Growth Phase?

**Alessandro Bessi [1], Mariangela Guidolin [2,*] and Piero Manfredi [3]**

[1] Department of Economics, University of Messina, Via Cesare Battisti, 98, 98122 Messina, Italy; alessandro.bessi@studenti.unime.it
[2] Department of Statistical Science, University of Padua, Via Cesare Battisti, 241, 35121 Padova, Italy
[3] Department of Economics and Management, University of Pisa, Via Cosimo Ridolfi, 10, 56124 Pisa, Italy; piero.manfredi@unipi.it
* Correspondence: mariangela.guidolin@unipd.it

**Abstract:** The National Energy and Climate Plans (NECPs) of the EU Member States have established comprehensive goals for 2030 to speed up the process of energy transition. Though Italy was an innovator in the area of photovoltaics (PV) up until 2014, the subsequent collapse and stagnation of its PV market have revealed an intrinsic fragility, which makes reaching international targets in the future unclear. This study used the Generalized Bass Model in a multi-phase extension to offer insights into and perspectives on the Italian PV market with the use of new data at finer temporal and market-size scales. Our model-based evidence suggests the possibility of a remarkable structural change corresponding to the "reboot" period after the pandemic crisis. In this period, small- and large-scale PV adoption, after years of parallel pathways, have taken largely different routes. On the one hand, small-scale adoption exhibited a fast decline with the end of the post-COVID-19 incentive programs, thus confirming the traditional "addiction to incentive" issue. On the other hand, during the "reboot" period, large-scale installations showed, for the first time, symptoms of exponential growth. This is consistent with the possibility that, finally, this sector is on an autonomous growth path. The latter evidence might represent a critically important novelty in the Italian PV landscape, where firms—rather than households—take the lead in the process. Nonetheless, future public monitoring and guidance are both urgent requirements to avoid a further catastrophic fall in the residential PV market and to make the sustained growth of the large-scale PV industry a robust phenomenon.

**Keywords:** innovation diffusion models; PV energy; energy policy; structured shocks; small- vs. large-scale PV systems

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## 1. Introduction

The need to address the ongoing energy crisis and enact timely energy transition programs has prompted many countries to foster new investments in renewable energy (RE) sources and therefore reduce their reliance on fossil fuels. Solar panels, electric vehicles, and heat pumps are recording exceptional growth rates at the global level, thus confirming their role in curbing GHG emissions in the upcoming years. Despite these positive trends, the energy transition process remains highly heterogeneous around the globe, with the RE increases in China, the EU, and the USA leading the way [1]. Such an uneven distribution of green policies, paired with poor international cooperation, is hindering a more timely transition, and the prospect of keeping the global temperature's increase below 1.5 remains challenging [1]. Additionally, carbon emissions have not yet reversed their growing trend (+1% in 2022 [2]), which is concerning, as an average decrease of 6% per year needs to be achieved in order to stay on track with the 2030 international targets. According to the International Energy Agency (IEA), achieving the targets of the Paris Agreement will require at least triple the investment in RE technologies worldwide by 2030 [3]. In pursuit of this challenge, the EU Green Deal aims to legally bind the EU to reduce its GHG emissions by 55% before 2030 and to reach carbon neutrality by 2050 [4], thereby pledging to make the EU the first climate-neutral regional area. Nevertheless, the EU's plan to take the lead in this energy transition process was hampered by the breakout of COVID-19 in 2020. To comply with the delays and to foster new investments, the EU enacted the "Fit for 55" package, whereby it asked its Member States to update their National Energy and Climate Plans to stay on track with the emission targets. Like other EU countries, Italy submitted its updated National Energy and Climate Plans in mid-2023, whereby it considerably expanded its long-term targets with respect to RE. According to the updated document, Italy is planning to achieve at least 131 GW of renewable installed capacity by 2030 (see [5] for a detailed overview). Italy's transition plan has set considerably high targets for increasing its use of solar energy, which is expected to lead the national energy transition by reaching at least 80 GW of installed PV capacity by 2030. With 25 GW of installed PV capacity at the end of 2022, a more than three-fold capacity increase in seven years would be required to reach the updated targets.

According to [6], the attractiveness of solar energy is fast improving, and an irreversible global solar tipping point may have already passed, where solar energy has gradually come to dominate global electricity markets. As an effect of this increasing importance in recent years, the scientific interest in solar energy (which is considered a major part of the impetus behind the energy transition process), has grown considerably. Besides the technological aspects, a wide body of research has devoted its attention to trying to identify the main drivers of solar PV adoption and growth. Recent reviews on these factors may be found, for instance, in [7,8]. As a general remark, the majority of the literature on the adoption process of solar PV agrees on the crucial role of both public incentives and policies (see, e.g., [9–11]) and consumer behavioral traits, such as individual attitudes and motivations (e.g., [12], as well as peer effects, e.g., [10,13,14]). In this paper, we focused on the market growth of solar PV in Italy, and—through a carefully selected modeling approach that is motivated by this increasing importance of solar energy in the energy transition process—we also tried to capture the effect of both public incentives and the behavior of the final adopters. The Italian case has been the object of some relevant research contributions, namely [15–17]. In [15], the authors found that there were two phases in the development of the PV market in Italy. In the first phase, large power generators had the role of "market followers" as they showed a substantial absence of industrial leadership, whereas, in the second phase, large utility companies became leaders in the PV market. In [16], the impact of regulatory simplification was found to have a positive effect on the increase of installed capacities in medium-to-large plants. In [17], several factors were found to be speeding up the installation process, such as improvements in PV technology with declining prices, the increased availability of battery storage systems, the growing use of electric appliances, the uptake of electric cars, and increased environmental awareness. These pieces of evidence, which were based on the past research conducted on the Italian scenario, lead to some aspects that we further investigated in our analysis, namely the crucial role of large-scale PV installations, including (besides utilities, commercial, and industrial plants), the need to account for the effect of policy measures and the presence of some triggering market factors (i.e., the diffusion of continuously progressing technologies), which are able to stimulate the final choices of the consumer.

In particular, we aimed to describe the historical trajectory of the PV market in Italy in this study by trying to capture, as much as possible, the underlying dynamics that are present due to both internal and external market factors. In doing so, we employed the well-established approach of innovation diffusion models, whereby we started from the seminal ideas of [18] and operated on the assumption that the growth of energy sources follows the laws of innovation diffusion [19,20], i.e., where both the behavior of consumers and the market conditions play significant and distinguishable roles [18,21].

In the literature, the innovation diffusion approach, which is based on the simple Bass model (BM), [20], has been employed on the growth of solar energy for both *explanatory* and *predictive* purposes, e.g., to study the role of innovation consumers and word-of-mouth dynamics, or to make projections about a market's evolution based on observed data. For example, in [22], the authors used the Bass model to study the diffusion of solar PV in Ontario, Canada, and they found that technology awareness and energy cost savings have a significant effect on the probability of adoption, thus reinforcing the need for effective communication in order to better explain the investment criteria, feed-in tariffs, and environmental factors. In [23], the Bass model was used to project the solar PV expansion in Brazil, although the authors acknowledged that the brevity of the historical data prevented obtaining robust estimates. Moreover, a well-known drawback of the simple Bass model is its inability to measure the effect of external factors that can dramatically change the shape of the diffusion process, which results in its departure from the classical bell-shaped curve. For diffusion modelers, the Italian PV market has been a challenging case study since its onset, with its complex trend being characterized by a sequence of stop-and-go epochs that are, most often, driven by public incentives. Given this critical role played by public incentives in the take-off of the Italian PV market, we will specifically use the Generalized Bass Model (GBM), [24], which is especially suited to describing innovation diffusions that are perturbed by *structured* shocks. In addition, this model has also already been applied to the PV market [25]. Structured shocks are perturbations of a diffusion phenomenon that show an identifiable pattern, as is often the case for external policy interventions. Guseo [26] was the first to use the GBM for representing diffusion trajectories that have been perturbed by structured shocks. Additionally, to the best of our knowledge, no model-based explanation has yet been proposed to explain the current critical phase of the Italian PV market, including the exceptional incentivization phase that was adopted to reboot the Italian economy after the pandemic crisis (which had no equivalent in the EU region [27]). This paper aims to fill this gap. In particular, we will analyze the Italian PV market by focusing on the possibly different dynamics of small- vs. large-scale PV installations, and this will be conducted on the assumption that these processes may obey different market rules and react differently to external incentives.

From a methodological point of view, we propose a new formulation of the Generalized Bass Model that considers separate phases of the diffusion, which we have called the *multi-epoch GBM*. The ensuing results will be used for an explanatory purpose, that is, interpreting past trends, as well as for a predictive purpose, i.e., developing future scenarios for PV energy. The novelty of our contribution relies on the insights offered by using PV data in a more granular way, that is, providing specific analyses for small- and large-scale PV installations within a novel modeling approach. This has led to a possibly richer understanding of the current dynamics of the PV market in Italy.

The rest of the study is structured as follows. In Section 2, we describe the main incentive programs set up in Italy to stimulate PV adoption, thereby providing a useful background for the subsequent interpretation of the modeling results. In Section 3, we describe the data used in the analyses and the innovation diffusion models employed. Section 4 contains an illustration of the main results. In Section 5, we discuss the most important pieces of the model-based evidence regarding the evolution of the PV market in Italy. Section 6 includes our main conclusions, where limitations and potential improvements of the work are discussed.

## 2. The PV Energy Market in Italy: A Summary of Incentive Programs

Certain common threads characterize the whole development of the Italian PV market, which we will summarize here. The PV energy history in Italy underwent a pivotal turning point after 2005 with the introduction of a new incentive program: the Italian Energy Bill (2005–2007) [28]. Prompted by the 2001 EU directive [29], the Energy Bill scheme introduced a net metering and a Feed-in-Premium (FIP) system, which was granted for 20 years, in order to stimulate the deployment of new PV systems nationwide. Both consumers and businesses could benefit from the premium fees with small tariff variations that were applied in accordance with the installation's scale. The first Energy Bill was especially limited in scope, providing a 0.5 GW cap to incentivize new plants and setting a national PV energy target of 1 GW for 2015. The program was widely acclaimed by the market, thus prompting the government to extend the range of incentives with a second energy bill (2008–2010) [30], where a further 1.2 GW was funded. Additionally, administrative procedures were simplified and the 1 MW cap for the maximum incentive power was removed. The broadened benefits brought by the second energy bill allowed for more opportunities for both large- and small-scale plants, which resulted in an increased momentum to the demand for connections to the grid, even after the 1.2 GW cap was reached. To meet the requests made during the moratorium period, the Italian Government enacted the Salva Alcoa act [31], which allowed installations that were constructed before 2010 to benefit from the high tariffs set with the second energy bill. In addition, the Salva Alcoa act was not constrained by any power cap. This, paired with the concurrent sharp price decrease of PV modules [32], led to a boom of PV adoptions, which ultimately resulted in an overlapping of its effect with the third energy bill (2010–2011) [33] (which meant that the third bill was only partially utilized). Despite the reduction in the incentive's volume, large capacity increases were recorded during the period of the fourth energy bill (2011–2012) [34], where an additional 4 GW were funded. Finally, the fifth energy bill (2012–2013) [35] marked the transition from the existing FIP system to a much less remunerative FIT system, thus encouraging self-consumption uses rather than grid injections alone. This, coupled with the limited budget assigned, led to a dramatic decline in adoptions, which precluded the prolonged market stagnation that occurred afterward once the Energy Bill program expired with no further renewal. While temporarily making Italy a global leader in solar-installed capacity, the energy bills largely affected the private financial burden. The offered fees were, in fact, entirely funded through a compulsory leverage on electricity bills, which led to an up to 30% increase in energy expenditures, thus making the policy unsustainable. The extent and the socio-economic impact of the energy bills are still being discussed in the literature. A comparison between similar European FIT systems [36] identified Italy's subsidies as the most remunerative in the EU. Furthermore, focusing on the Italian market, Di Dio et al. [37] assessed the five phases of the energy bills, and they reported a lack of a proper control mechanism for granting subsidies. Poponi et al. [38] criticized the cost effectiveness of the energy bills when analyzing the PV learning curves, and they suggested that a more "diluted" policy measure would have resulted in less financial burden. To date, the energy bill program remains the only Italian policy to have directly subsidized PV installations, both at the consumer and business level, whereas more recent policies have shown a higher degree of specificity, as reported in Table 1. Among the relevant follow-up programs, the Ecobonus [39] has been active since 2013. The scheme was designed to foster energy renovation measures, promote energy efficiency upgrades, and drive the integration of RE sources to existing household and non-commercial buildings, as invoked by the 2010 EU directive [40]. Unlike the energy bill scheme, which granted fees for the energy produced, the Ecobonus Investment Tax Credit (ITC) allowed one to modify the final upfront investment cost expenditure by granting a 50% tax credit for new PV installations. Nonetheless, the Ecobonus proved to be dramatically ineffective in sustaining adoptions between 2014 and 2019. The year 2020, on the other hand, marked a new resurgence of residential PV adoptions. Motivated to better cope with the unprecedented economic crisis generated by the COVID-19 pandemic, Italy complemented the existing Ecobonus scheme with a new ITC program [41] (not cumulative), which was later renamed the "Superbonus 110%". This program sought to reboot the Italian economy by pumping resources into the housing industry and to, consequently, subsidize PV adoptions. This measure offered an exceptionally generous tax credit that was equal to 110% of the sustained investment, which has not been equaled in any EU countries [27]. Furthermore, the scheme also offered the opportunity to transfer tax credits to third parties (i.e., financial institutions), thus allowing claimants to reduce (or even eliminate) their upfront investment costs. The scheme was widely acclaimed by the market and led to an almost EUR 70 million public expenditure by the end of 2022, thus ultimately forcing the Italian government to not extend the program for 2023 in order to cut credit transfers. It should be noted that, though the 110% tax credit was gradually reduced afterward, operative construction sites could still fully benefit from the incentives in accordance with the achieved progress stage. On the other hand, following the end of the energy bill period, the landscape of small and large businesses has been characterized by several minor interventions. A subsidized depreciation system was introduced in 2015 [42], which allowed for an increased acquisition cost of tangible assets (in relation to income taxation) and indirectly subsidized PV adoptions. The broad scope of the scheme, which involved most firms' capital goods, did not provide a strong emphasis for new PV installations, thus resulting in weak PV adoptions. In trying to regain momentum, a new supporting program (FER-1) was decreed in the second half of 2019 [43]. The incentive measure established a new FIT scheme for large-scale PV plants (>20 kW), one that was attainable through a two-fold tendering system. A public registration (which was constrained by especially limited power caps) was set for smaller plants (<1 MW), while auction systems were established for larger plants (>1 MW). As most available FER-1 quotas were shared with wind power projects, the decree attained particularly limited success in fostering new PV capacity additions. Lastly, starting from 2020, the already mentioned 2015 Super Depreciation system was replaced by a 6% tax credit and subsidized loans rates [44]. A detailed overview of the main incentive programs introduced by the Italian governmental to support, directly or indirectly, the PV market is reported in Table 1.

**Table 1.** Italy 2005–2023. The main incentivizing interventions on PV energy that are relevant for the present analysis. (*) indicates ongoing policies that were renewed for 2024.

| **Policy** | **Epoch** | **Target** | **Key Features** |
|---|---|---|---|
| Energy Bill 1<br>Gov. Decree Jul. 2005 [28] | 2005–2007 | - Residential/households;<br>(single/multiple units)<br>- Commercial/industrial firms;<br>- Utilities. | - 20-year FIP systems for new PV installations;<br>- Net metering option for small-scale installations (<20 kW);<br>- A maximum incentivable power per single installation (1 MW). |
| Energy Bill 2<br>Gov. Decree Feb. 2007 [30] | 2007–2009 | | - Updated FIP fees;<br>- Simplified administrative procedures;<br>- Net metering options up to 200 kW;<br>- Removal of the 1 MW power cap. |
| Salva Alcoa Act<br>Gov. Decree Sept. 2010 [31] | 2010–2011 | | - The second energy bill tariffs were extended until 30 June 2010. |
| Energy Bill 3<br>Gov. Decree Oct. 2010 [33] | 2010–2011 | | - Update FIP fees |
| Energy Bill 4<br>Gov. Decree Jul. 2011 [34] | 2011–2012 | | - Updated FIP fees;<br>- Cumulative cap burden for beneficiaries (EUR 6 bn). |
| Energy Bill 5<br>Gov. Decree Sept. 2012 [35] | 2012–2013 | | - Switch from FIP to FIT;<br>- Update cumulative cap burden for beneficiaries (EUR 6.7 bn). |
| Ecobonus<br>Gov. Decree Aug. 2013 [39] | 2013–2024 * | - Residential/household (single/multiple units). | - A 50% tax credit for both new installations and those installed within building renovations;<br>- Increase in the time for tax credit reimbursement (10 years);<br>- Cap for new (single) installations (EUR 96,000);<br>- Incentivable power cap (20 kW). |
| Super Depreciation<br>Gov. Decree Dec. 2015 [42] | 2016–2019 | - Commercial/industrial firms; | - Utilities; - Expenditure depreciation coefficient (130%);<br>- A cap for new (single) installations (EUR 2.5 mln). |

**Table 1.** *Cont.*

| Policy | Epoch | Target | Key Features |
|---|---|---|---|
| FER 1<br>Gov. Decree Sept. 2019 [43] | 2019–2022 | - Commercial/industrial firms;<br>- Utilities. | - 20-year FIT system;<br>- Tendering procedures for new installations (<1 MW);<br>- Auction system for new installations (>1 MW). |
| New Tax Credit<br>Gov. Decree Dec. 2019 [44] | 2020–2024 * | - Commercial/industrial firms;<br>- Utilities. | - A 6% tax credit;<br>- A decrease in the time for tax credit reimbursement (5 years);<br>- Expenditure cap for new (single) installations (EUR 2 mln). |
| Nuova Sabatini<br>Gov. Decree Dec. 2019 [44] | 2020–2024 * | - Commercial/industrial firms. | - Subsidized loans rates;<br>- Expenditure cap for new (single) installations (EUR 4 mln). |
| Superbonus 110%<br>Gov. Decree Jul. 2020 [41] | 2020–2024 * | - Residential/household (single/multiple units). | - A 110% tax credit for new PV installations constructed within major energy-efficient structural improvements of existing buildings (conditionally reduced after 2022);<br>- Time set for tax credit reimbursement (5 years);<br>- Activity-dependent expenditure cap. |

## 3. Materials and Methods

### 3.1. Data Description

Timely and comprehensive data regarding the Italian electricity market are provided monthly by both the Italian Energy Services Operator (GSE) [45] and the Electricity Transmission Network Operator (TERNA) [46]. The series of the monthly installed capacity from February 2009 to October 2023 is displayed in Figure 1, whereby the first wave of installations between 2009 and early 2014 are shown, followed by the prolonged market stagnation between 2014 and 2021, with an eventual resumption starting in 2021. Both the first and second wave of installations appeared to be characterized by a high variability, possibly due to the monthly frequency of data, where some seasonal and autocorrelation components may be present. At the same time, such variability may be related to certain structural changes in the data, which were likely imputed due to policy interventions.

More granular information was obtained by splitting data according to installation size ($P$), as follows:

- $P_1 = P \leqslant 20$ kW;
- $P_2 = 20$ kW $\leqslant P < 200$ kW;
- $P_3 = 200$ kW $\leqslant P < 1$ MW;
- $P_4 = P \geqslant 1$ MW.

This choice was motivated by trying to achieve an adequate compromise between information relevance and parsimony. Indeed, the nation-wide data on Italy [45,46] do not include data at the adopter level (i.e., individual household vs. firms). However, there is substantial evidence [45] suggesting that small-scale installations ($P1$) were predominantly carried out by household consumers (at least 80%), whereas large-scale installations were almost perfectly matched (>99%) with firm installations. The disaggregated data offer interesting insights both in terms of the scale and shape of the observed trends (Figure 2). In particular, the trend of small-scale installations ($P1$), which are mostly represented by residential PV installations, markedly differs from that of the larger-scale installations ($P2$, $P3$, $P4$) during the energy bill epoch (2005–2013) but especially regarding the Superbonus ITC epoch. We also noted that the Fall of 2014, after the end of the energy bill period, was dramatic for especially large plants ($P3$, $P4$), which demonstrated almost no adoptions for years, thus suggesting a strong stochasticity.

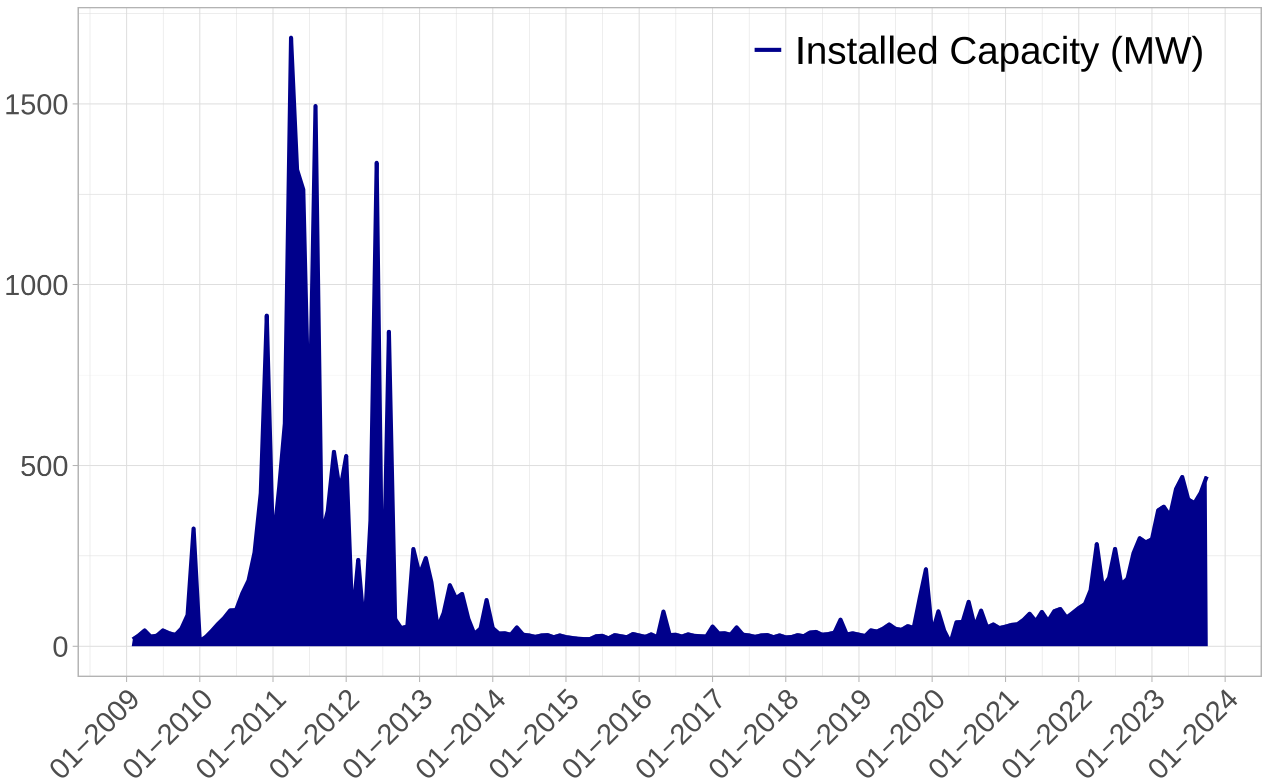


**Figure 1.** The monthly PV installed capacity, in MW, from February 2009 to October 2023 in Italy.

Based on this evidence, we decided to aggregate the last three categories $P2 + P3 + P4$ (Figure 3), therefore splitting the market into two groups, namely *small-scale* PV installed capacity (P1) and *large-scale* PV installed capacity ($P2 + P3 + P4$). Our purpose was to characterize the mutual differences as much as possible.

### 3.2. Innovation Diffusion Models: The Generalized Bass Model

Innovation diffusion models are a well-established approach for studying the adoption of energy technologies; they are based on the hypothesis that energy sources behave similarly to products that need to be accepted by a market. Starting from the previously cited seminal works of [18,26], the literature on innovation diffusion models in energy markets has rapidly expanded in the last 20 years, and there have been several reviews conducted that have highlighted their importance as modeling tools to understand the dynamics of adoption of energy sources and the evolution of energy markets, e.g., [47–49]. The most famous innovation diffusion model is the Bass Model (BM) [20], which describes an innovation diffusion process via the following first-order differential equation:

$$z'(t) = \left\{ p + q\frac{z(t)}{m} \right\} \{m - z(t)\}, \quad t > 0, \tag{1}$$

where $z(t)$ represents the cumulative adoptions at time $t$ and its instantaneous rate of change $z'(t)$ represents the instantaneous adoptions curve. In (1), instantaneous adoptions ($z'(t)$) are proportional to the residual market $m - z(t)$, where $m$ is the market potential, i.e., the maximum scale of the diffusion process, which is expressed through a hazard rate given by the sum of the *innovation rate* ($p > 0$) and the product of the *imitation rate* ($q > 0$) times the current market share ($z(t)/m$):

$$h(t) = p + q\frac{z(t)}{m}. \tag{2}$$

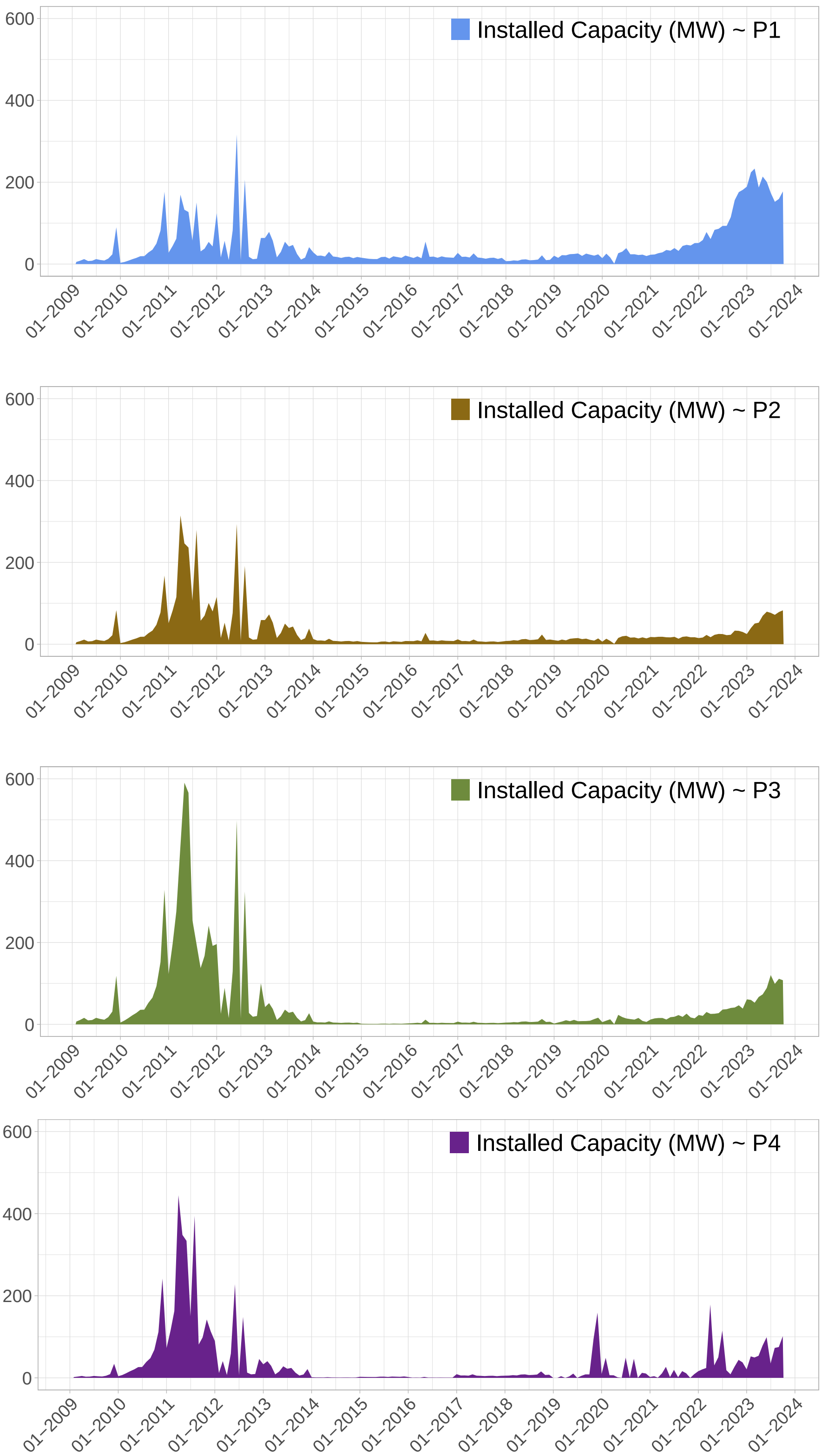


**Figure 2.** Monthly installed capacity of PV panels from February 2009 to October 2023 in Italy divided according to installation size. Top left: $P_1 = P \leqslant 20$ kW adoptions; top right: $P_2 = 20\text{ kW} \leqslant P < 200$ kW adoptions; bottom left: $P_3 = 200\text{ kW} \leqslant P < 1$ MW adoptions; and bottom right: $P_4 = P \geqslant 1$ MW adoptions.

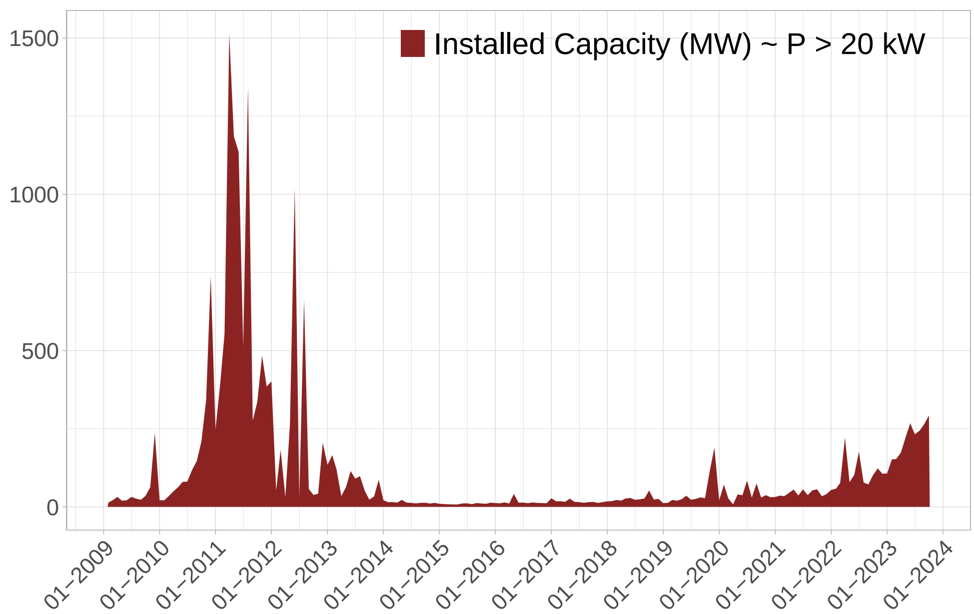


**Figure 3.** Monthly installed capacity of the large-scale ($P2 + P3 + P4$) PV panels (P > 20 kW) from February 2009 to October 2023 in Italy.

The underlying hypothesis is that an innovation diffusion process evolves by adoptions that are driven by the behavior of consumers who make decisions based on either of the following: (i) their own beliefs thanks to institutional communication and mass media (innovators) or (ii) imitating the behavior of others through a learning process that has been typically termed *word of mouth* (imitators). Typically, innovation diffusions are characterized by the dominant effect of word of mouth, whereas the innovative component is usually sub-dominant and plays a role at the beginning of the process. The BM has been usefully employed to model the adoption dynamics of solar photovoltaic energy, such as, for example, in [25,50,51]. In these studies, however, it is also highlighted that most of the diffusion processes of RE sources are characterized by non-smooth and highly perturbed trajectories, and this is due to the typically fragile role of innovators and the need to remedy this weakness with certain external measures that are able to stimulate adoptions, such as policy actions.

To capture the effect of these external actions and efficiently describe the perturbations observed in the data, a suitable generalization of the BM, namely the Generalized Bass Model (GBM) [24], has proven crucial [25,50,51]. The GBM extends the BM by multiplying its hazard rate ($h(t)$) by a general *perturbation function* $x(t)$, thus yielding the following equation:

$$h_{GBM} = \left\{ p + q\frac{z(t)}{m} \right\} x(t), \quad t > 0, \quad x(t) > 0. \tag{3}$$

Here, we follow and update the first proposal made by [26], which has been successfully employed in many contexts (for a review, see, for instance, [49,52]), whereby the function $x(t)$ is defined as a combination of *structured* shocks through meaningful parametric forms.

In considering a diffusion process perturbed by a sequence of $k$-structured shocks, the intervention function $x(t)$ may be specified as

$$x(t) = 1 + \sum_{i=1}^{k} g_i(t; \theta_i), \tag{4}$$

where the function $g_i(t; \theta_i)$ represents the i-th shock and $\theta_i$ is its parametric vector.

A first type of structured shock may have a *rectangular* form, $F1$, as follows:

$$g_{F1}(t;\theta_{F1}) = c\, I_{[a,b]}(t) \qquad \theta_{F1} = (c,a,b), \tag{5}$$

where the scale parameter $c$ denotes the shock's intensity and can assume positive or negative values according to its contribution in accelerating or slowing down the diffusion, while $[a,b]$ $(b > a)$ is the interval where the shock occurs. While having a simple structure, rectangular shocks are not suited to portray effects that change over time. A simple shock showing a dynamic intensity is given by the *exponential* shock as follows:

$$g_{F2}(t;\theta_{F2}) = c\, e^{(-b\,(t-a))} I_{(a,\infty)}(t) \qquad \theta_{F2} = (c,a,b) \quad b > 0, \tag{6}$$

where an initial impulse ($c$) is exponentially reabsorbed by the market with a time scale $1/b$.

If time is required for the shock to reach its maximum effectiveness, various formulations can be used to modulate a gradual initial growth before exponential re-absorption takes place. In this work, the following two variations of the exponential shock are proposed:

$$g_{F3}(t;\theta_{F3}) = c(t-a)\, e^{(-b(t-a))} I_{(a,\infty)}(t) \qquad \theta_{F3} = (c,a,b) \quad b > 0, \tag{7}$$

$$g_{F4}(t;\theta_{F4}) = c(t-a)^2\, e^{(-b(t-a))} I_{(a,\infty)}(t) \qquad \theta_{F4} = (c,a,b). \quad b > 0. \tag{8}$$

Shock $F3$ represents an initially linear perturbation of the hazard rate, whereas shock $F4$ shows a parabolic one.

### *3.3. Multi-Epoch Innovation Diffusion*

The patterns of energy markets are often complicated, as is also apparent in Figure 1. This suggests the possibility that such trends are the outcome of a complex superposition of phenomena, which possibly result from the interplay between spontaneous adoptions by agents with non-steady policy interventions. The lack of stability in policy interventions might add to the typical shocks accounted for by the GBM, where further layers of complexity result in changes in the entire model structure as the diffusion progresses. Such complexities might be due to, e.g., governmental interventions and technological innovations that might open the market to new sub-populations that were previously excluded. Therefore, the GBM—despite its richness—might also not be sufficient for handling such complexity. Rather, a *multi-epoch* formulation might be necessary to capture such *structural changes*. An example of such a multi-epoch GBM formulation might be the following hazard rate:

$$h_{ME} = \sum_j h^j_{GBM}(p_j, q_j, m_j)\, \xi_j, \tag{9}$$

where $\xi_j$ represents the indicator function of the time interval $[a_j, b_j]$. The underlying idea is that a GBM-type diffusion takes place over different intervals of time (*epochs*), which are characterized by different propensities in adopting different market pressures and evolving market potential through different policy interventions.

### *3.4. Model Estimation*

The nonlinear least squares method (NLS) has been accepted and used as the most reliable method of estimation in the innovation diffusion literature. Following [52], the structure of a nonlinear regression model is as follows:

$$w(t) = \eta(\vartheta, t) + \varepsilon(t), \tag{10}$$

where $w(t)$ is the observed response; $\eta(\vartheta, t)$ is the deterministic component (which can describe either instantaneous or cumulative diffusion processes) and is dependent on the parameter vector $\vartheta$ and time $t$; and $\varepsilon(t)$ is the error term, which is typically assumed to follow standard hypotheses. Traditionally, models like the BM and the GBM are estimated on cumulative adoption data by using the model closed-form solutions [20,24]. The goodness of fit is typically evaluated through the $R^2$ value [52]. However, when it is necessary to select between different models, relying on $R^2$ may not be the most convenient solution and other indexes may be used instead, such as the Akaike Information Criterion (AIC) [53].

## 4. Results

In this section, we illustrate the results of our modeling procedure by separately considering the series of the monthly *residential* PV installed capacity ($P \leqslant 20$ kW) and the *large* PV installed capacity ($P > 20$ kW). Given the lack of detailed data on the number of individual adoptions, we will take the figures of installed capacity as the primary proxy. In both applications, several different modeling options were tested, and the model selection between them was conducted via a combination of statistical considerations (i.e., goodness of fit and parameter significance) and the results' interpretability.

### *4.1. Small-Scale PV*

#### 4.1.1. Single GBM Fit

Here, we apply the GBM (3) to the entire $P1$ dataset. We report the corresponding estimates for the model that were eventually selected: a GBM with five shocks (Table 2) and the related graphical fit in Figure 4. First, the innovation and imitation parameters $p$ and $q$ (both statistically significant) had a comparable magnitude ($p = 0.0012$/month and $q = 0.0042$/month). This was found to be at odds with many standard innovation diffusion processes, which are typically imitation-driven (i.e., where $q$ is much larger than $p$) [49]. Moreover, the innovation rate was not negligible compared to other works on PV energy [25,51]. However, as already pinpointed in the introduction, the diffusion appeared to be dominated by external shocks, ones that were mostly attributable to the interventions enacted within the energy bill (2005–2013) and the Superbonus ITC (2021–2023) period. A well-evident first exponential shock (form $F2$) was identified starting in November 2009 ($a_1 = 10.0$ months), although its parameters were not found to be statistically significant. Rather than suggesting the absence of a shock in that period, the lack of significance might be explained by the particularly short duration of the shock (three months), with just one datum to estimate its intensity and no visible degrading effect afterward. This lack of significance may also be related to data collection, since a consolidated system was not completely developed at the time. The second shock (form $F4$), which started in June 2010 ($a_2 = 17.2$ months), had a moderate intensity ($c_2 = 0.821$), thus implying a positive boost to adoptions and a mild re-absorption speed ($b_2 = 0.256$/month). This corresponded to an average absorption time of about 4 months. While the shock captured the qualitative traits of the effect of the second and third energy bills well, it could not capture the scale of the monthly oscillations. This problem can be easily adjusted by, e.g., taking moving averages of data or any other smoothing procedure (this was caught effectively, for example, in [25], albeit on yearly data instead). The third identified shock (form $F2$, which started in April 2012 with an $a_3 = 38.8$ months) had a longer re-absorption time (a $b_3 = 0.143$/month, roughly equivalent to 7 months) compared to the second one. This shock reproduced the qualitative trend of the adoptions during the fourth and fifth energy bill well, while suffering the same shortcomings in the reproduction of the scale. This third wave can be mainly tied to installations prompted by the fourth energy bill [54], thereby suggesting how—despite nominally lasting only one year—the fourth energy bill was characterized by a greater ability to persist over time compared to previous shocks. After the prolonged stationary phase, which occurred during 2014–2019, a fourth shock ($F4$) was identified in August 2019 ($a_4 = 127.6$ months), and it was characterized by a low intensity ($c_2 = 0.0035$). Unlike previous shocks, the estimated re-absorption speed was almost negligible ($b_4 = 0.0002$/month) while remaining highly significant, thus suggesting a highly persistent (i.e., especially long-lasting) effect of perturbation. Finally, the fifth shock ($F3$, which started in June 2022 with an $a_5 = 161.2$ months) displayed a slow, yet not significant, re-absorption time ($b_5 = 0.074$/month). The lack of significance can be attributed to the mingling of the shock's reabsorption process with the saturation of the second diffusion wave, which potentially concealed the real extent of the shock. This shock can be directly tied to the effect of the Superbonus 110% ITC bill, which was set after the first COVID-19 wave to reboot the Italian economy through special aid to the housing industry.

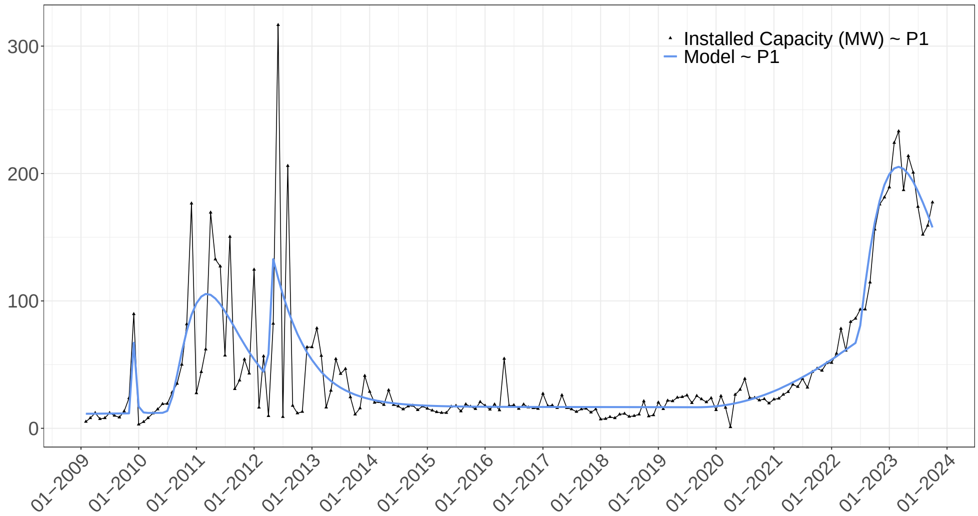


**Figure 4.** Fit of the GBM with five shocks for small-scale PV installed capacities.

**Table 2.** The GBM (five shocks: $F2 + F4 + F2 + F4 + F3$) estimates over the entire dataset of the small-scale installed capacities ($P1$).

| GBM (five shocks: $F2 + F4 + F2 + F4 + F3$) | | | MSE = 806 | AIC = 1221 | $R^2 = 0.9998$ |
|---|---|---|---|---|---|
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | $p$-value |
| $m$ | 9773 | 1426 | 6979 | 12,568 | <0.001 *** |
| $p$ | 0.0012 | 0.0002 | 0.0007 | 0.0016 | <0.001 *** |
| $q$ | 0.0042 | 0.0008 | 0.0026 | 0.0058 | <0.001 *** |
| $a_1$ | 10.0 | 27.4 | −43.7 | 63.8 | 0.715 |
| $b_1$ | 2.480 | 70.356 | −135.416 | 140.376 | 0.972 |
| $c_1$ | 12.734 | 359.325 | −691.530 | 716.998 | 0.972 |
| $a_2$ | 17.2 | 0.5 | 16.2 | 18.2 | <0.001 *** |
| $b_2$ | 0.256 | 0.017 | 0.222 | 0.290 | <0.001 *** |
| $c_2$ | 0.821 | 0.162 | 0.504 | 1.137 | <0.001 *** |
| $a_3$ | 38.8 | 0.273 | 38.3 | 39.4 | <0.001 *** |
| $b_3$ | 0.143 | 0.009 | 0.126 | 0.160 | <0.001 *** |
| $c_3$ | 6.767 | 0.554 | 5.681 | 7.854 | <0.001 *** |
| $a_4$ | 127.6 | 0.9 | 125.8 | 129.4 | <0.001 *** |
| $b_4$ | 0.0002 | 0.00001 | 0.00018 | 0.00022 | <0.001 *** |
| $c_4$ | 0.0031 | 0.0002 | 0.0027 | 0.0035 | <0.001 *** |
| $a_5$ | 161.2 | 0.8 | 159.7 | 162.7 | <0.001 *** |
| $b_5$ | 0.074 | 0.078 | −0.067 | 0.215 | 0.304 |
| $c_5$ | 2.260 | 0.728 | 0.834 | 3.687 | 0.002 ** |

Signif. levels: 0 '***'; 0.001 '**'; and 0.1 ' ' 1.

### 4.1.2. The Two-Epoch GBM Fit

As remarked in Section 4.1.1, the presence of the exceptionally long-lasting shock initiated by the end of 2019 might have been diagnostic of the fact that the *small-scale* installations' dynamics might have observed a *structural change*. This structural change might have involved all the structural parameters ($p$, $q$, and $m$) that appeared in the basic Bass hazard (2), and it possibly could have been through a modulated action of the involved shocks. This suggests that a basic GBM model, as used in Section 4.1.1, might not be suited to describing the entire diffusion, thus calling for a multi-phasic dynamic modeling instead—as is described in Section 3.3. For the sake of simplicity, we searched for a two-phasic dynamic by fitting a two-epoch GBM, which was achieved by splitting the $P1$ dataset into two temporal segments, namely the period between February 2009 and December 2020, as well as the period between January 2021 and October 2023. As this second period largely overlapped with the reboot of the Italian economy after the two dramatic pandemic waves of March and October–November 2020, we termed this second period the "Reboot" period. The choice of the two segments was made *exogenously* by a direct inspection of the time series, which was achieved by letting the second period begin in correspondence with the first instance of evidence of a new structural wave. The best model that was eventually selected included three shocks ($F2$, $F4$, and $F2$) during the first period and only one during the second one ($F4$). The estimates and model fitting for both epochs are illustrated in Table 3 and Figure 5, respectively. A comparison with the "Single GBM fit", as described in Section 4.1.1, provides the following additional results.

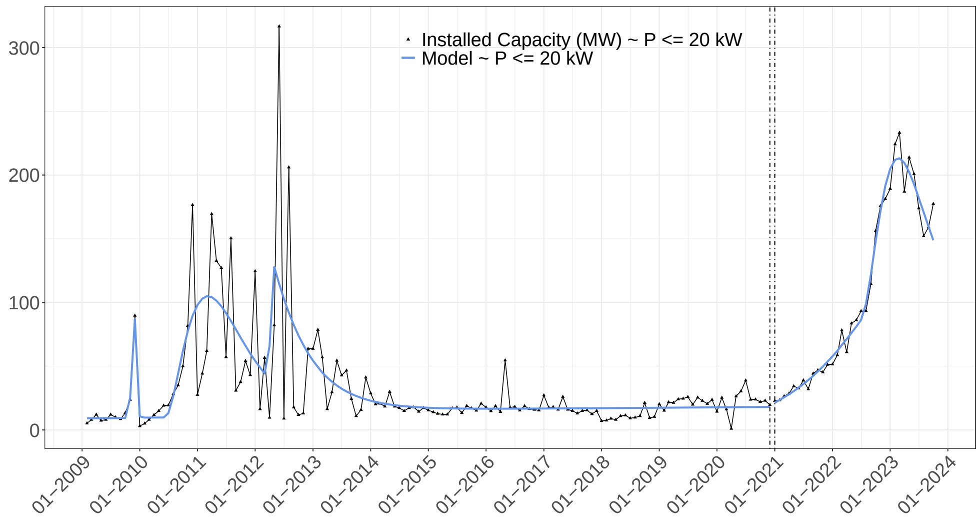


**Figure 5.** A two-epoch GBM fit for the small-scale PV installed capacities. The first epoch (February 2009 to December 2020) was fitted by a three-shock GBM (F2 + F4 + F2), and the second epoch (January 2021 to October 2023) was fitted by a one-shock GBM (F4).

We found a high coherency with the previous experiment with respect to the first period. In particular, the same shock structure and essentially the same parameter estimates were identified, thus confirming both the starting points and intensities of all the involved shocks. The first shock resulted in a non-significant impact, thus confirming that its identification was mostly due to the lack of more detailed data. Certain differences were detected for the baseline diffusion parameters, which showed an imitation rate that was 62% higher ($q = 0.0068$/month) than in the single GBM case, albeit still being comparable in scale. The estimated market potential was lower ($m = 7087$ MW), thereby suggesting that subsequent governmental intervention might have brought a significant expansion of the market potential. Instead, with respect to the reboot period, the model structure showed a remarkable change when compared to what was detected in the previous experiment. The most interesting news was represented by the dramatic change in the Bass imitation coefficient ($q = 0.0929$/month), which showed a 14-fold increase when compared to the first period (and was even larger compared to the estimate of the unified GBM in Section 4.1.1). Only one shock (which was highly significant) was identified by the best model, thereby essentially reflecting the fueling role of the Superbonus ITC bill. The visual fit to the data was highly satisfactory, as well as the model selection indices, thus suggesting that the structural change hypothesis is a sound one. However, the model predicted a rapid decline in the momentum fueled by the Superbonus incentive, thereby suggesting the possibility that the *small-scale* PV market could catastrophically fall at the end of the incentive epoch; tellingly, this was not distinct from what occurred at the end of the energy bill period.

**Table 3.** The multi-epoch GBM estimation results for the small-scale PV installed capacities. The first epoch was fitted with a three-shock GBM, while the second epoch was described through a one-shock GBM.

| GBM (four shocks: *F*2 + *F*4 + *F*2) | | | MSE = 1137 | AIC = 1030 | $R^2$ = 0.9994 |
|---|---|---|---|---|---|
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | *p*-value |
| $m$ | 7087 | 709 | 5696 | 8477 | <0.001 *** |
| $p$ | 0.0015 | 0.0003 | 0.0010 | 0.0020 | <0.001 *** |
| $q$ | 0.0068 | 0.0013 | 0.0042 | 0.0094 | <0.001 *** |
| $a_1$ | 10.0 | 43.0 | −74.3 | 94.0 | 0.817 |
| $b_1$ | 2.636 | 113.894 | −220.592 | 225.864 | 0.982 |
| $c_1$ | 14.644 | 630.434 | −1220.985 | 1250.272 | 0.982 |
| $a_2$ | 16.9 | 0.6 | 15.7 | 18.2 | <0.001 *** |
| $b_2$ | 0.255 | 0.021 | 0.215 | 0.296 | <0.001 *** |
| $c_2$ | 0.748 | 0.172 | 0.410 | 1.085 | <0.001 *** |
| $a_3$ | 39.0 | 0.308 | 38.4 | 39.6 | <0.001 *** |
| $b_3$ | 0.167 | 0.015 | 0.137 | 0.196 | <0.001 *** |
| $c_3$ | 6.469 | 0.621 | 5.251 | 7.687 | <0.001 *** |
| GBM (one shock: *F*4) | | | MSE = 63 | AIC = 153 | $R^2$ = 0.9999 |
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | *p*-value |
| $m_{(>2021)}$ | 5425 | 278 | 4880 | 5970 | <0.001 *** |
| $p_{(>2021)}$ | 0.0038 | 0.0002 | 0.0034 | 0.0042 | <0.001 *** |
| $q_{(>2021)}$ | 0.0929 | 0.0022 | 0.0886 | 0.0972 | <0.001 *** |
| $a_{1(>2021)}$ | 18.6 | 0.4 | 17.8 | 19.4 | <0.001 *** |
| $b_{1(>2021)}$ | 0.332 | 0.043 | 0.248 | 0.417 | <0.001 *** |
| $c_{1(>2021)}$ | 0.132 | 0.029 | 0.074 | 0.191 | <0.001 *** |

Signif. levels: 0 '***'; and 0.1 ' ' 1.

### 4.2. Large-Scale PV

Given the practical extinction of the large-scale PV market in Italy at the end of the energy bill epoch, no unified GBM could be fit for the entire period. This made the authors even more motivated to resort to the two-phasic approach that was followed in Section 4.1.2 for small-scale adoptions. Using the same temporal partition adopted in the previous Section 4.1.2, the best model was identified by the union of a GBM with three shocks (*F*2, *F*4, and *F*2) in the first period and a simple BM in the reboot period. The estimates and model fit are reported in Table 4 and Figure 6. Similarly to what was observed for the small-scale PV applications, the innovation and imitation parameters presented the same magnitude, i.e., $p = 0.0018$ and $q = 0.0082$, which led to similar conclusions being reached as were made in Section 4.1.2. Further similarities—except for shock intensity (which was much higher for large-scale PV)—could be seen in the similar estimated starting point and re-absorption time for the shocks that were identified during the energy bill epoch. The most relevant novelty concerns were instead focused on the second period, which was adequately fitted by a simple Bass model in its growing phase and without evidence of there being any presence of perturbations. Both the innovation and imitation rates were found to be highly significant. In particular, the imitation rate was eight-fold larger than the corresponding value estimated for the first period, which hinted at a radical change in the structure of the diffusion and was instead fully dominated by the shocks attributable to the energy bill epoch during the first period. This may suggest the possibility that the reboot epoch might represent the first symptom of the onset of an autonomous diffusion process for large-scale PV.

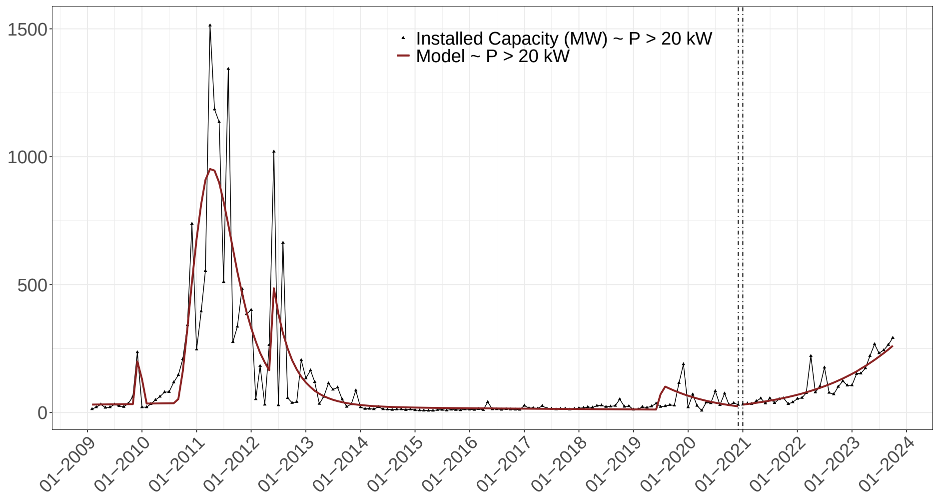


**Figure 6.** The fit of the four-shock GBM and BM (after 2021) for the large PV installed capacities.

**Table 4.** The four-shock GBM and BM (after 2021) for the large PV installed capacities.

| GBM (four shocks: *F*2 + *F*4 + *F*2 + *F*2) | | | MSE = 18,283 | AIC = 1443 | $R^2$ = 0.9994 |
|---|---|---|---|---|---|
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | *p*-value |
| $m$ | 17,012 | 885 | 15,278 | 18,745 | <0.001 *** |
| $p$ | 0.0018 | 0.0004 | 0.0010 | 0.0026 | <0.001 *** |
| $q$ | 0.0082 | 0.0048 | −0.0012 | 0.0176 | 0.090 · |
| $a_1$ | 10.0 | 2446 | −4784 | 4806 | 0.996 |
| $b_1$ | 23.897 | 1,363,722 | −2,672,822 | 2,672,870 | 0.999 |
| $c_1$ | 183 | 10,473,319 | −20,527,144 | 20,527,512 | 0.999 |
| $a_2$ | 19.2 | 0.4 | 18.4 | 19.9 | <0.001 *** |
| $b_2$ | 0.287 | 0.014 | 0.260 | 0.314 | <0.001 *** |
| $c_2$ | 2.726 | 0.795 | 1.167 | 4.284 | <0.001 *** |
| $a_3$ | 40.0 | 0.4 | 39.3 | 40.7 | <0.001 *** |
| $b_3$ | 0.169 | 0.025 | 0.120 | 0.219 | <0.001 *** |
| $c_3$ | 10.267 | 2.686 | 5.003 | 15.531 | <0.001 *** |
| $a_4$ | 125.4 | 1.5 | 122.4 | 128.4 | <0.001 *** |
| $b_4$ | 0.0001 | 0.166 | −0.326 | 0.326 | 0.999 |
| $c_4$ | 8.456 | 4.143 | 0.335 | 16.577 | 0.043 ** |
| BM | | | MSE = 2804 | AIC = 300 | $R^2$ = 0.9977 |
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | *p*-value |
| $p_{(>2021)}$ | 0.00056 | 0.00002 | 0.00053 | 0.00060 | <0.001 *** |
| $q_{(>2021)}$ | 0.0682 | 0.0015 | 0.0654 | 0.0711 | <0.001 *** |

Signif. levels: 0 ‘***’; 0.001 ‘**’; 0.05 ‘.’; and 0.1 ‘ ’ 1.

### *4.3. Scenarios*

In summarizing the results of the previous two subsections, a dual behavior appeared to emerge from the comparison between the small- and large-scale adoptions. While *small-scale* adoptions seem to have entered a rapid declining phase—possibly resulting from the exhaustion of the Superbonus incentive and therefore not differing from the Energy Bill epoch—the *large-scale* adoptions showed symptoms of continuing growth that were not sustained by conspicuous market incentives. This dualism was possibly strengthened by the commonalities showed by the different classes (*P*2, *P*3, and *P*4) of large-scale PV adoptions, as shown in Figure 7, which were also found to exist in the corresponding Bass trends for each power class (see Table 5). As is apparent from Figure 7, the exponential trend was shared by all large-scale classes, i.e, *P*2, *P*3, and *P*4, despite the fact that they were not targeted by the Superbonus 110% measure.

**Table 5.** BM (after 2021) for *P*2, *P*3, and *P*4.

| BM (*P*2) | | | MSE = 932 | AIC = 236 | $R^2$ = 0.9896 |
|---|---|---|---|---|---|
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | *p*-value |
| $p_{(P2)}$ | 0.00064 | 0.00003 | 0.00057 | 0.00070 | <0.001 *** |
| $q_{(P2)}$ | 0.062 | 0.0029 | 0.056 | 0.068 | <0.001 *** |
| BM (*P*3) | | | MSE = 432 | AIC = 210 | $R^2$ = 0.9973 |
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | *p*-value |
| $p_{(P3)}$ | 0.00048 | 0.00002 | 0.00045 | 0.00051 | <0.001 *** |
| $q_{(P3)}$ | 0.076 | 0.002 | 0.073 | 0.079 | <0.001 *** |
| BM (*P*4) | | | MSE = 3360 | AIC = 280 | $R^2$ = 0.9793 |
| Parameter | Estimate | Std. Error | Lower C.I. | Upper C.I. | *p*-value |
| $p_{(P4)}$ | 0.00063 | 0.00005 | 0.00052 | 0.00073 | <0.001 *** |
| $q_{(P4)}$ | 0.066 | 0.005 | 0.057 | 0.075 | <0.001 *** |

Signif. levels: 0 '***'.

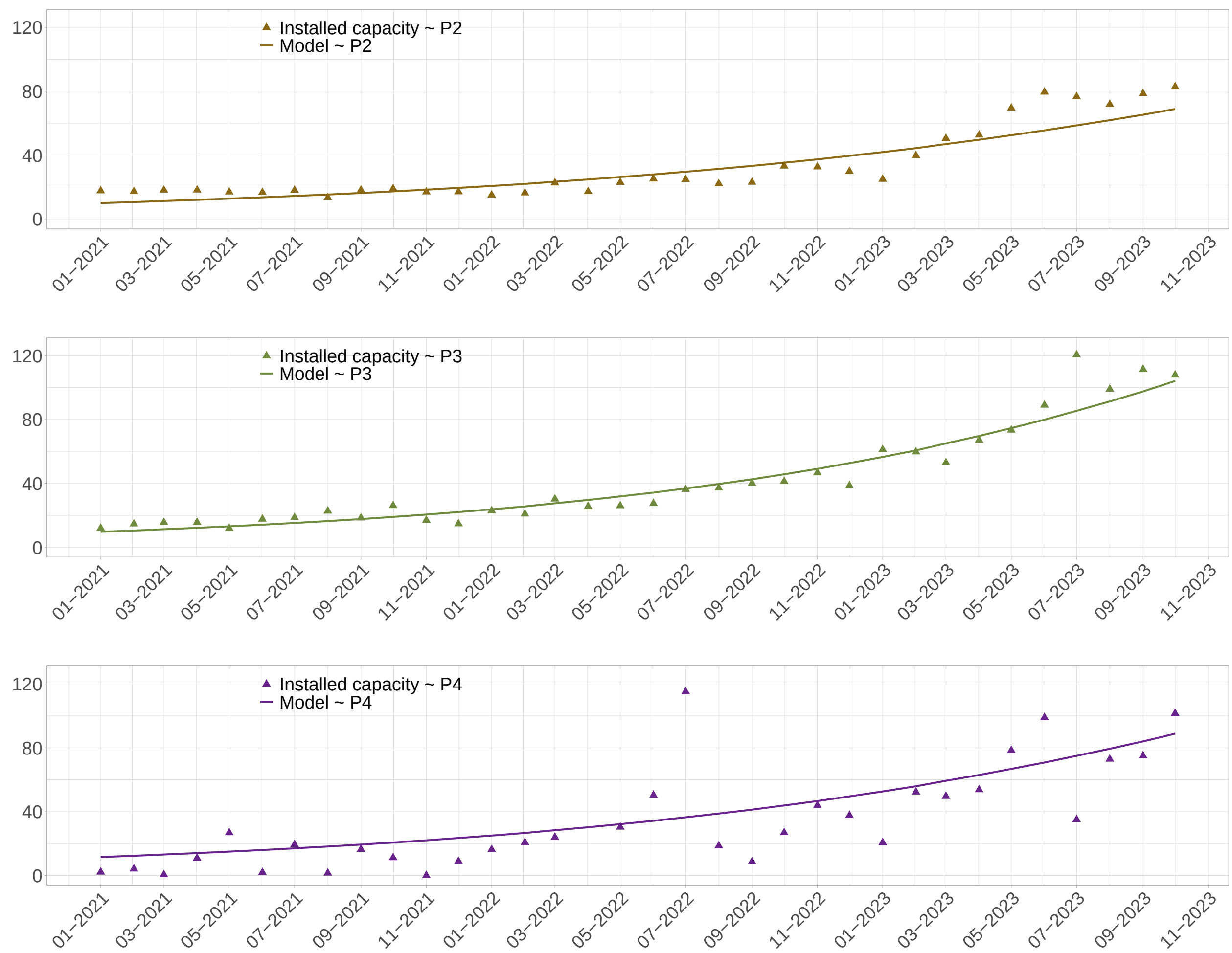


**Figure 7.** BM (after 2021) for the large PV installed capacities: estimated trajectories for *P*2, *P*3 and *P*4.

Though we are aware that these arguments are speculative, they also, in turn, suggest that large-scale PV might represent the driver of future trends in the Italian PV market. We have consistently provided a scenario of the future market evolution as follows: the small-scale PV projections were generated by prolonging the trend identified by the two-phasic GBM that was presented in Section 4.1.2. The large-scale PV projections were generated by assuming that the 2030 target (which is defined in NECP2030 and taken here as the residual market starting in October 2023) will be achieved by the contribution of large-scale PV only. Additionally, the contribution of each large-scale segment to the 2030 target was taken, for the sake of simplicity, as being proportional to the cumulative levels achieved at the end of the second period. The resulting scenario (Figure 8) was drawn as persisting until the end of 2027, which is the same horizon adopted by the IEA in its last report [55]. The graph shows the full extinction of the contribution of small-scale PV and the parallel Bass-type increase in monthly large-scale PV adoptions when considering them against their 2030 NECP target.

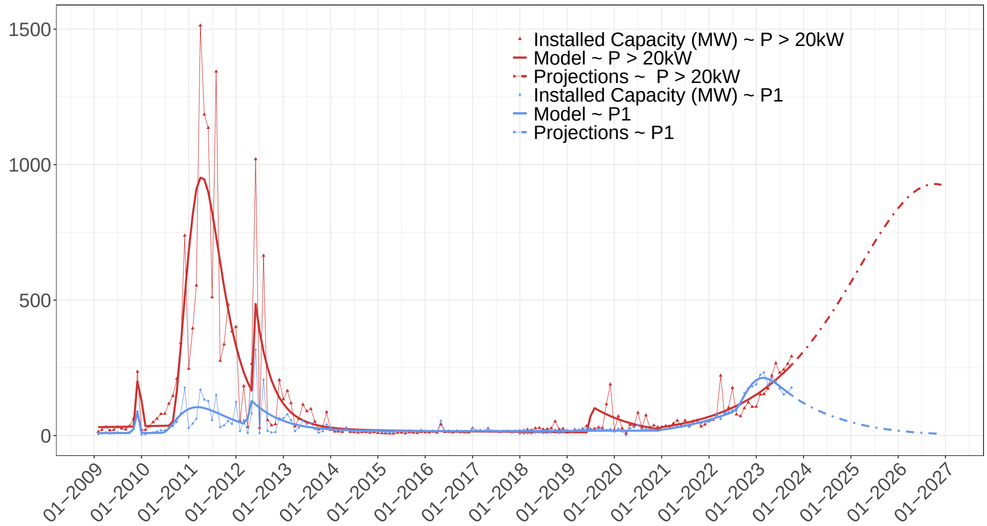


**Figure 8.** The Italian PV market: a time series of the small- and large-scale PV adoptions with their corresponding best fits until October 2023, as well as their projections up till 2027.

## 5. Discussion

Though Italy has been an acknowledged innovator in the area of RE [2], the long-term trends of its PV market have been largely controversial with continuous stop-and-go policies and a dramatic collapse of adoptions after the end of the energy bill incentivization epoch (2014). This has made future achievements toward international targets unclear. This study used univariate diffusion models, namely the Generalized Bass Model in a multi-phasic extension, to offer insights and future perspectives on the Italian PV market from a starting point of February 2009. While the proposed approach shares certain commonalities with previous works on PV diffusion [25,50], the availability of new data with finer temporal (monthly rather than yearly) and market size (i.e., the different power scales of installations) details has allowed us to bring fresh novelties to the discussion. In particular, by disaggregating the PV adoptions according to PV power classes, our model-based analysis over the period 2009–2023 suggests, as its main finding, the possibility of an important structural change (which was initiated after the COVID-19 outbreak). Such a structural change was witnessed via the divergence between the trajectories undertaken by small- and large-scale PV adoptions during the “reboot” period, which was after the most dramatic phase of the COVID-19 pandemic. Overall, this suggests the possibility that the responses of these different sub-populations of adopters to the underlying supporting policy measures are at odds with what was observed in the preceding epoch, which instead showed a remarkable symmetry between the adoption patterns of all the different market segments by power size. From a modeling viewpoint, these results were documented by the strong commonalities in the model parameters (i.e., those tuning the shock terms to the public incentives, as well as the key Bass parameters) during the first phase and by their clear divergence during the reboot phase. The collapse of adoptions at the end of the energy bill period yielded a subsequent stagnation epoch that lasted several years, as was described in [25] as evidence of a pervasive addiction to incentives by the Italian public. The symptoms of a new collapsing trend at the end of the Superbonus ITC scheme seem to confirm this addiction to incentive as a persistent feature of the long-term trends of Italian residential PV installations. Conversely, large-scale adoptions during the reboot epoch were well fitted by a Bass model in its exponential phase of growth, with an imitation coefficient that was 15-fold higher than the corresponding value during the first period. This is suggestive of a regime change where spontaneous market forces are finally in place. Further supporting evidence lies in the fact that all the power segments of large-scale PV adoptions exhibited especially similar temporal trends with strongly comparable values in their imitation rates. The current situation of the Italian PV market is quite uncertain and, consequently, our results should be taken, rather than as established knowledge, as useful insights for policy making. Therefore, more data are required to establish the robustness of both the sustained growth of large-scale PV installations, as well as the (further) potential collapse of the residential segment. Nonetheless—based on the awareness of the long-term history of the Italian PV market, its traditional addiction to incentives, and the uncertainty surrounding the current phase of the energy transition—we believe that, to achieve the aforementioned international targets, a double external policy guidance should be maintained in the future. A first policy direction should be to target residential investments, as this work has further confirmed that the majority of small energy consumers are still not inclined to take charge of the energy transition process—i.e., they possibly only undergo risky investments in the presence of major advantages. Further evidence of this still low propensity on the part of small energy consumers is the protracted stagnation of the 2014–2020 period, which is when a further incentive program, namely the Ecobonus program, proved to be completely ineffective. The second direction should ensure that the evidence of achievement by large-scale PV installations with respect to the ability to grow autonomously is not just a temporary phenomenon, but rather one that becomes a truly self-sustained one.

## 6. Conclusions

In its 2022 report, the studies in reference [55] and its related dashboard (the International Energy Agency (IEA)) provided country-level energy projections of PV adoptions for a wide number of world countries. These projections showed the sustained exponential growth trend of the aggregated Italian PV market over the considered horizon (i.e., until 2027). This yielded the optimistic interpretation that the market had finally achieved a self-sustained growth path. This has also been backed by other previous studies [25,50], where it was effectively documented that the Italian PV market has been suffering from evident addiction to incentives; however, our current findings challenge this optimistic view regarding the future phases of the Italian ecological transition process. Indeed, the present analysis, based on diffusion models and disaggregating small- and large-scale PV adoptions, suggests a more controversial type of behavior. On the one hand, the fast decline of small-scale adoptions with the end of the post-COVID-19 incentive programs, despite the huge room still available for further investment [56], seems to confirm the "addiction to incentive" issue [25]. On the other hand, large-scale adoptions are showing, for the first time, symptoms of exponential growth that are consistent with the fact that this segment has achieved an autonomous growth path. This aspect of the exponential trend is surely an important novelty in the Italian PV landscape, thereby suggesting the possibility that the PV diffusion process, in its current phase, is driven by firms rather than households. However, the uncertainty surrounding this critical point makes it necessary to wait for further data to confirm or disprove this hypothesis.

At a more general level, several issues should be acknowledged. First, learning about and making comparisons regarding the PV trends with other countries, especially within the EU region, will be important in this phase [55,57]. Indeed, the continued stop-and-go approach to supporting RE policies in the EU zone has often resulted in "cyclical" evolutions in the market. This has been caused by the pursuit of cyclically renewed international targets [58–60] in the involved EU countries. Another important issue relates to the volatility of the current geopolitical scenario that has been induced by the Russian–Ukrainian war and its impact on the energy transition process. The aforementioned 2022 report by IEA [55] qualified the current phase as having "unprecedented momentum for renewables", and this was sparked by the war. Future research will be in the position to clarify the true impact of this momentum. In addition, based on these premises (which were obtained from the international context), we believe that the current Italian situation is still greatly uncertain and will require decision makers to continue in carefully monitoring and guiding the process with two main aims: first, to avoid a further fall of the residential PV market (as was observed in the past) and, second, to make the current symptoms of the sustained growth of large-scale PV a robust phenomenon. At a further higher level, we believe that the current phase of the ecological transition is highly critical, such that achieving a full understanding of the socio-economic and cultural determinants of (and barriers to) renewable energy adoption represents a key theme of the current research agenda. Indeed, several studies (from 2012 onward) on the Italian PV market have suggested that grid parity for PV has been reached [15,61]. However, the period between the end of the energy bill epoch and the onset of the COVID-19 pandemic has seen a collapse of the Italian large-scale PV market, thus demonstrating that the existing barriers were able to overwhelm the achievement of the grid parity. This is not to say that there has been a fall in the small-scale adoptions that were documented in this manuscript at the end of the last incentive round (Superbonus ITC). All these phenomena instead suggest significant barriers, which seem to confirm the concept of the "addiction to incentives" that was coined in our previous work [25]. Nonetheless, it seems reasonable to believe that the phenomenon of the large volatility of gas prices that has followed the Russian–Ukrainian war (which is especially relevant for the Italian case), jointly with the continuous decline of PV module prices and the decline of PV return times, should eventually remove all the current barriers to adoption.

From a methodological point of view, we should acknowledge that our approach suffers from certain limitations. The adopted multi-phasic GBM model was fitted by exogenously choosing the boundary date separating the two phases. A possible improvement could be selecting the boundary dates endogenously. By using a univariate approach, the model does not account for the possible interplay with other energy sources (e.g., natural gas).

Lastly, no replacement process for old PV panels was accounted for. While it is reasonable to assume that such an issue is currently negligible, the population of Italian PV installations is growing old, thus suggesting that reaching the goals of the 2030 NECPs will require coping with an increasing need for replacement installations or, at least, the refurbishing of existing plants. Notwithstanding these limitations, we believe that the insights in this paper are of relevance for understanding the Italian PV market.

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**Data Availability Statement:** All data used in this study are publicly available at https://www.gse.it/Dati-e-Scenari_site/statistiche_site (accessed on 12 December 2023) and https://www.terna.it/it/sistema-elettrico/dispacciamento/fonti-rinnovabili (accessed on 12 December 2023).

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