PV-related rooftop fires – national statistics and the impact of reporting methods

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Abstract. PV-related fires have caused significant property damage over the last decade, and their numbers are still rising, thus potentially undermining solar power's intended contributions towards sustainability. Robust solutions are needed to ensure risk reduction, and incident reporting is an important part of the risk analysis process. Statistics on the adverse events provide a good insight into the more prevalent failure modes and establish the failure frequency. An assessment of the data on PV-related fires shows that Italy can expect about 10 fires per GW annually, while Slovenia can expect about 37 fires per GW annually, compared to a previously established number for an international average of 29 fires per GW. Although the rates for both countries are in the same order of magnitude as the international average, the differences can be attributed to different methods of data collection, as well as to some differences in legislation and installation requirements in the two countries. Importantly, while acceptable risk levels are typically in the order of 10^{-6}, the observed rates are in the order of 10^{-4}, which is in a range that demands immediate risk management actions.

1. Introduction

The recent exponential growth of photovoltaic (PV) systems worldwide is driven by the intent to produce affordable renewable energy without relying on carbon-based energy sources [1]. Apart from the global trend of departing from energy sources that contribute directly to climate change, various national and supranational entities are also encouraging new PV installations to promote energy independence from sources of energy production outside of their borders [2], [3]. While the exponential growth of PV systems is key to addressing global energy needs, this rapid expansion brings new safety concerns, particularly in the area of fire hazards. As the presence of PV systems on buildings increases, it is essential to ensure that safety measures, especially concerning fire risks, are adequately addressed.

There have been many major fires associated with PV systems. In addition, some researchers have identified fire risk as one of the critical aspects in ensuring the safety of PV systems [4]. In general, the risk is usually considered as the probability of the unwanted event and the negative consequences that the event can cause [5]. PV systems have been recognised to influence both

[†] The paper and its entire content do not represent the official position of this co-author's organisation (CNVVF).

parts of the equation – that is, they are both increasing the probability of a fire and worsening the consequences in the event of a fire. As PV systems consist of various electrical components that can fail and lead to ignition, it is not surprising that many of the electrical components of the PV system (connectors, cables, inverters, safety switches, junction boxes, optimisers...) have been reported through investigations of previous fires as the ignition causes [6], [7], [8]. Efforts to improve their reliability are already underway through the development of various standards. Some manufacturers are also working on enhanced or entirely new products to increase the reliability and robustness of PV systems.. However, apart from the elevated probability due to the potential failure of the electric components, the PV assembly itself can provide conditions for a fire to spread. Even if the components, installation and maintenance are all done with an appropriate level of quality, the presence of a PV system on the building can allow a flame to spread faster and further, leading to worsened negative consequences compared to cases without the PV installation [9], [10], [11].

To effectively mitigate these fire risks, gathering and analysing statistical data on PV-related fires is crucial. These statistics highlight the current state of safety and provide insights into potential future risks. Some of the work that has already been done in the past has tried to look into the extent of PV-related fires globally [12]. The data from four countries (Australia, Germany, Italy, and the USA), coming from different parts of the world, was collected and compared. The data was assessed statistically, and since the methodologies employed to collect the data varied significantly, they needed to be rearranged and harmonised to compare them. The weighted number came out at 29 fires annually per GW of installed PV systems. The research has already highlighted some issues with the variances in the methodologies used for the collection of data in different countries. Other research groups are exploring methods to enhance global data collection for better comparability [13], and robust proposals exist to improve future statistical practices. Meanwhile, the current work reinforces the previously established figures and strengthens the case for adopting more harmonised collection methodologies.

2. Methodology

The methodology for this study, presented in Figure 1, involves collecting and analysing the data on PV-related fires from Italy and Slovenia, which are selected as European countries that have a large difference in population and have different requirements and regulations when it comes to the installation of PV systems on roofs. Although both countries employ similar systems for the collection of data, there are some important differences in the methodology. Still, a comparative analysis of the data from the two countries will provide valuable insights, especially when contrasted with data published in the past. Both sets include data for the total number of PV-related fires and the number of PV installations for each year. This was employed to potentially portray the influence of the size of the installation on the fire risks of PV installations.

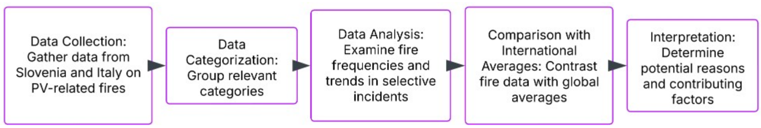

Figure 1. Diagram of the methodology for establishing the fire frequencies of PV systems on roofs.

The data for Slovenian PV-related fires was obtained from the Slovenian Administration for Civil Protection and Disaster Relief (URSZR) [14]. URSZR is responsible for collecting reports on the incidents reported to the emergency number (112) to which the firefighters were deployed.

In mid-2023, URSZR updated the reporting form, including a category for PV-related fires, and so the data for this type of incident was gathered for the period between 30. 5. 2023 and 19. 7. 2024. The data about the capacity of PV systems installed in Slovenia were obtained from the PV portal [15], managed by the Laboratory of Photovoltaics and Optoelectronics, Faculty of Electrical Engineering, University of Ljubljana [16]. It was decided to treat the data separately for each year. The reported number of fires was used to calculate the number of incidents per week in the interval of a given year. From this, the estimated total number of fires in the year was derived.

The Italian set on PV-related fires was compiled from the annual statistical database of incidents collected by the Italian National Fire Brigade (Corpo Nazionale Vigili del Fuoco, CNVVF), gathering all the reports coming from all fire brigades. A specific "Photovoltaic Panels" category was introduced in the CNVVF's system back in 2014 to capture the phenomenon of PV-related fires better. Before 2014, all the data had to be manually reviewed by textual searches through the free-text fields of the database using specific keywords "photovoltaic fire", "solar panel fire", or similar, which may lead to inconsistencies [17]. The data used for both aforementioned papers [12], [17] included Italian data until 2015. Here, later data is considered, including data from 2015-2024. The difference between the Italian and the Slovenian data is that the Slovenian data also includes cases where other parts of the PV system (a connector, a cable or an inverter...) ignited. On the other hand, the Italian numbers of panels fire events reflect PV-related incidents where the PV module(s) were involved in the fire. A separate query was done on the dataset to obtain the numbers for fires involving PV module(s) only on all sorts of buildings (no ground-mounted, agrivoltaics, floating, etc.), labelled in Table 1 Italy b(uildings). The Italian data on the capacity of the PV installations were obtained from reports by the Gestore dei Servizi Energetici (GSE) [18], and for the year 2024, data was obtained from TERNA S.p.A., the grid operator [19].

3. Results and discussion

Table 1 shows the gathered data in the columns without a background, and the analysis outcomes in the columns with a grey background. Some uncertainties arise from the data, for instance, due to the extrapolation of fire numbers for years 2023 and 2024 for the Slovenian data. This could introduce some uncertainty, as it assumes that fire frequency during the recorded periods is representative of the entire year. Another level of uncertainty is related to the URSZR's data collection methodology. What is not entirely clear are the criteria according to which an incident is categorised as related to the PV system. This may only include fires involving PV system parts or also cases where a building fire occurred, but the presence of a PV system, although not affected by fire, hindered firefighters' efforts to extinguish it and was still included. These considerations ought to be considered to improve the reliability of the final numbers.

As shown in Table 1, the data for Slovenia and Italy exhibit some notable differences in the frequency of PV-related fires, yet both countries align with the numbers observed in the previous international study [12], where the weighted annual average was set at 29 fires per GW of installed PV systems. The Italian data, with incidents ranging from 5 to 13 fires per GW annually (and between 9 and 15 for fires on buildings), contrasts with Slovenia's higher rates, between 35 and 39 fires per GW, but all mostly fall within the same order of magnitude.

Figure 2 shows the growing trend in the annual number of PV-related fires per installed GW in Italy. The reason for the omission of the Slovenian data can be attributed to the smaller overall sample size and the possible inclusion of other types of incidents that could contribute to the differences in trends across countries. These discrepancies can be attributed to differences in data categorisation and data collection methods. As mentioned in the methodology, the Italian data represents a more selective set of incidents, including only events where the PV modules were involved in fires, as opposed to Slovenian data, where the category is broader and includes all different events where any part of the PV system was involved in the fire. As a result, the numbers obtained for Italy are lower, but they still provide a reasonable estimate of the expected outcomes.

Table 1. Collected data and calculated overall numbers of PV-related fires per GW of installed systems and per 10 000 installed systems

Country	Year	Number of fires	Capacity of installed PV systems [GW]	Number of PV installations (in 1000)	Average installation size [kW]	fires/ GW	fires/10 000 installations
Slovenia*	2023	44	1.1	49	22.9	39.2	9.0
Slovenia*	2024	49	1.4	65	21.6	35.0	7.6
Italy	2015	97	18.9	688	27.5	5.1	1.4
Italy	2016	139	19.3	732	26.3	7.2	1.9
Italy	2017	152	19.7	774	25.4	7.7	2.0
Italy	2018	186	20.1	822	24.5	9.3	2.3
Italy	2019	203	20.9	880	23.7	9.7	2.3
Italy	2020	181	21.7	936	23.1	8.4	1.9
Italy	2021	191	22.6	1016	22.2	8.5	1.9
Italy	2022	295	25.1	1225	20.5	11.8	2.4
Italy	2023	379	30.3	1597	19.0	12.5	2.4
Italy	2024	337	37.1	-	-	9.1	-
Italy b	2019	142	13.0	-	-	10.9	-
Italy b	2020	141	13.7	-	-	10.3	-
Italy b	2021	151	14.5	-	-	10.4	-
Italy b	2022	243	16.7	-	-	14.6	-
Italy b	2023	292	21.1	-	-	13.9	-

*The Slovenian data was extrapolated to full years from 215 days in 2023 and 200 days in 2024.

Individual risk is often defined as the probability per year that any one person will suffer a harmful effect from an exposure to an activity, and an acceptable individual risk level is usually set at around 10^{-6} [20]. Looking at the column for number of fires/10 000 installations in Table 1, it shows that a few fires per 10 000 installations can be expected each year (in the order of 10^{-4}), which means that the numbers are about two orders of magnitude too high.

The number of PV-related fires is also closely related to the quality of materials and parts used for the construction of the PV system, the quality of work that the installers perform, as well as the quality of maintenance during the lifetime of the system's operation [21]. In the past, it has already been noted [12] that government financial incentives have created favourable conditions for unskilled installers to start working on PV systems simply because there was sufficient demand in the market and a shortage of qualified installers. This led to an increase in the number of fires related to PV systems, which tended to decrease after the end of the incentives [4].

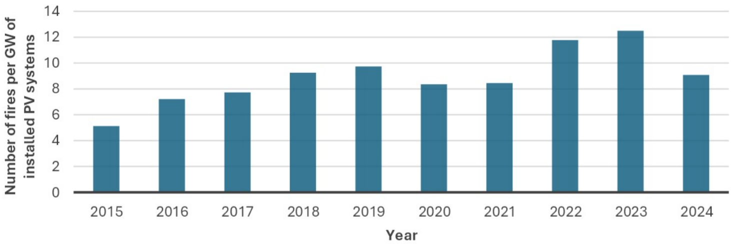

Figure 2. The annual number of rooftop PV-related fires in Italy per GW of installed power

The above uncertainties arising from the extrapolation of Slovenian data and the incomplete data for Italy in 2024 present challenges for drawing definitive conclusions. These gaps underscore the need for more comprehensive data collection and more explicit criteria for incident classification to ensure accurate and reliable fire safety assessments.

4. Conclusions

This study confirms a concerning statistic in PV-related fires, showing a consistent growth in the number of fires/GW over the years in the Italian dataset, which covers consistent data over a decade. Comparing the overall data with the number of fires in buildings suggests that these types of PV systems may pose a higher risk. Critically, incident rates for both Italy and Slovenia exceed acceptable risk thresholds by roughly two orders of magnitude, indicating significant shortcomings in current installation, maintenance, and quality control practices. These findings highlight the urgent need for a more targeted, systemic approach to fire risk management of PV systems. Improved data collection and closer collaboration between regulators, industry leaders and safety professionals are essential to ensure the safe expansion of solar energy in the future while maintaining public safety and the reliability of renewable energy.

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References

[1] Solar Power Europe, “Global Market Outlook For Solar Power 2025-2029,” May 2025. [Online].
[2] European Parliament, *Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings*. 2024. Accessed: Jun. 26, 2024. [Online].

[3] European Parliament, *Communication from the Commission to the European parliament, the European council, the council, the European economic and social committee and the committee of the regions REPowerEU Plan*. 2022. Accessed: Aug. 07, 2024. [Online].
[4] P. Cancelliere, "PV electrical plants fire risk assessment and mitigation according to the Italian national fire services guidelines," *Fire Mater.*, vol. 40, no. 3, pp. 355–367, Apr. 2016, doi: 10.1002/fam.2290.
[5] S. Kaplan and B. J. Garrick, "On The Quantitative Definition of Risk," *Risk Analysis*, vol. 1, no. 1, pp. 11–27, Mar. 1981, doi: 10.1111/j.1539-6924.1981.tb01350.x.
[6] M. Aram, X. Zhang, D. Qi, and Y. Ko, "A state-of-the-art review of fire safety of photovoltaic systems in buildings," *Journal of Cleaner Production*, vol. 308, p. 127239, Jul. 2021, doi: 10.1016/j.jclepro.2021.127239.
[7] P. Cancelliere, G. Manzini, G. Traina, and M. G. Cavriani, "PV modules on buildings – Outlines of PV roof samples fire rating assessment," *Fire Safety Journal*, vol. 120, p. 103139, Mar. 2021, doi: 10.1016/j.firesaf.2020.103139.
[8] Clean Energy Associates, "PV Rooftop Safety - Top 10 Safety Concerns," Clean Energy Associates. Accessed: Jul. 03, 2023. [Online].
[9] J. S. Kristensen, B. Merci, and G. Jomaas, "Fire-induced reradiation underneath photovoltaic arrays on flat roofs," *Fire and Materials*, vol. 42, no. 3, pp. 316–323, Apr. 2018, doi: 10.1002/fam.2494.
[10] J. S. Kristensen, F. B. M. Faudzi, and G. Jomaas, "Experimental study of flame spread underneath photovoltaic (PV) modules," *Fire Safety Journal*, vol. 120, p. 103027, Mar. 2021, doi: 10.1016/j.firesaf.2020.103027.
[11] J. S. Kristensen, B. Jacobs, and G. Jomaas, "Experimental Study of the Fire Dynamics in a Semi-enclosure Formed by Photovoltaic (PV) Installations on Flat Roof Constructions," *Fire Technology*, vol. 58, no. 4, pp. 2017–2054, Jul. 2022, doi: 10.1007/s10694-022-01228-z.
[12] N. A. F. Mohd Nizam Ong, M. A. Sadiq, M. S. Md Said, G. Jomaas, M. Z. Mohd Tohir, and J. S. Kristensen, "Fault tree analysis of fires on rooftops with photovoltaic systems," *Journal of Building Engineering*, vol. 46, p. 103752, Apr. 2022, doi: 10.1016/j.jobe.2021.103752.
[13] M. Manes *et al.*, "Closing Data Gaps and Paving the Way for Pan-European Fire Safety Efforts: Part I—Overview of Current Practices for Fire Statistics," *Fire Technol*, vol. 59, no. 4, pp. 1925–1968, Jul. 2023, doi: 10.1007/s10694-023-01415-6.
[14] "Administration for Civil Protection and Disaster Relief," Portal GOV.SI. Accessed: Oct. 09, 2024. [Online].
[15] "PV portal - Sončne elektrarne v Sloveniji." Accessed: Oct. 09, 2024. [Online].
[16] "Laboratory of Photovoltaics and Optoelectronics, Faculty of Electrical Engineering, University of Ljubljana." Accessed: Oct. 09, 2024. [Online].
[17] Fiorentini, Luca, Marmo, Luca, Danzi, Enrico, and Puccia, Vincenzo, "Fire risk assessment of photovoltaic plants. a case study moving from two large fires: from accident investigation and forensic engineering to fire risk assessment for reconstruction and permitting purposes," *Chemical Engineering Transactions*, vol. 48, pp. 427–432, Jun. 2016, doi: 10.3303/CET1648072.
[18] Gestore dei Servizi Energetici (GSE), "National Survey Report of PV Power Applications in Italy 2023," Oct. 2024. [Online].
[19] TERNA S.p.A., "Terna: electricity consumption increases by 2.2% in 2024," TERNA S.p.A., Press Release, Jan. 2025. Accessed: Feb. 25, 2025. [Online].
[20] International Atomic Energy Agency, "Guidelines for Integrated Risk Assessment and Management in Large Industrial Areas," International Atomic Energy Agency, Vienna, 1998.
[21] G. Jomaas, A. Jug, and N. Rus, "Fire Safety Guideline for Building Applied Photovoltaic Systems on Flat Roofs," Slovenian National Building and Civil Engineering Institute (ZAG), May 2024. [Online].