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Fire incidents involving photovoltaic systems – An analysis of different national statistics

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ABSTRACT

With the increasing number of PV installations, reported PV-related fire incidents are receiving greater attention, although their quantification depends strongly on how such events are recorded. To manage fire safety risks in PV systems effectively, accurate statistics on the probability and consequences of these incidents are essential. National statistics from the UK, Italy, Sweden, and Slovenia were analysed to examine how differences in reporting methodologies influence the observed fire statistics. The findings indicate that different measures may be relevant for assessing ignition frequency. When comparing reported fire numbers, the rate ranges from approximately 4-11 fires per GW annually in the UK, Italy, and Sweden, to about 37 per GW annually in Slovenia. Similarly, the number of incidents per 100,000 installations was found to be approximately 5-22 for the UK, Italy, and Sweden, compared with 75 in Slovenia. These differences are likely influenced by variations in data collection methods and inclusion criteria across the countries. Swedish data also show notable differences in the various measures depending on system size. In the Swedish dataset, DC cables and connectors are the most frequently identified ignition source. Regarding consequences, about 68 % of fires remain confined to the PV equipment, while 24 % damage adjacent surfaces. In 5 % of cases, significant fire spread occurred, while in 3 % the building was completely destroyed. The similarities and differences in the national statistics highlight the need for harmonised data collection to enable meaningful comparison and support data-driven fire safety measures for PV systems.

1. Introduction

Climate change remains one of the most pressing global challenges of our time, driving an urgent transition to renewable energy sources. In response, solar energy has become a key element of the decarbonisation strategy in the European Union (EU). In line with the REPowerEU plan [1] and the European Green Deal [2], the EU adopted Directive (EU) 2024/1275, also known as the *EU Solar Standard* [3], which introduces gradual obligations for installing PV systems on several distinct building types, depending on their type and size, including technical and economic feasibility. The requirements become more demanding after 2026, with all suitable buildings required to comply by 2030. More specifically, EU Member States shall ensure the deployment of suitable solar energy installations as outlined in Fig. 1 [4]. Here, it is important to emphasise that installing PV systems on 'all suitable buildings' means that hospitals, schools, kindergartens, hotels, museums, churches, warehouses and historic buildings alike will be equipped with PV. All these building categories have already suffered from PV-initiated and PV-related fires. The European Commission has recognised the importance of PV fire safety through an ongoing tender for 'Guidance on fire safety linked to the electrification and renovation of buildings' [5], where one of the major tasks is related to PV fire safety.

This legislative shift is expected to significantly increase both the capacity and the number of solar power installations across Europe. In

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Sweden alone, the number of grid-connected solar power systems rose from approximately 10,000 in 2016 to nearly 300,000 by 2024 [6]. Furthermore, projections indicate that growth will continue [7]. On a European scale, solar capacity increased from 207 GW in 2022 to 308 GW in 2024, representing an increase of almost 50 % in just two years [8]. These numbers include all installation types, such as ground-mounted, building-applied, and building-integrated systems, but usually exclude off-grid systems. Although off-grid systems contribute to fire incidents, there are rarely any means of including them in reports on capacity and numbers. As the numbers and capacities increase, associated fire risks are being highlighted more [9,10]. Several research studies focus on different aspects of fire risks associated with solar power systems, such as the fire dynamics of solar panels and roof construction [11–15], and fault detection and mitigation [16–18]. However, while some statistical data are available [19–21], in the German case, data about consequences are also provided, but these reports are generally limited to a country and not related to the total number of installations or system capacity. In addition, there is limited information on differences in the underlying statistical data from different countries, suggesting that more comprehensive data on frequencies, ignition sources and extent of consequences for PV systems are needed.

In the past four years, Europe has experienced several PV-related fires in various types of buildings, including hospitals [22], school complexes [23], museums [24], and storage warehouses [25–28]. The consequences included the evacuation of a maternity ward [22], 1200 pupils losing their school building [29], and the closure of a museum for two years [30]. Additionally, some warehouses, where PV systems are typically among the largest, suffered PV-related fire losses involving thousands of PV modules [31] or even total loss of the building, with damages reaching €50 million [32] or nearly €100 million [33]. All these likely represent only a small proportion of cases, as shown in Fig. 2, since smaller PV-related fires often do not reach the media or do not require firefighter intervention.

Claims that the data under-represent the actual extent of incidents are supported by safety audit and inspection data. A safety audit report covering over 600 PV systems across multiple countries found that 97 % of audited installations have major safety concerns [34]. Separately, monitoring programme utilising autonomous drone-based inspections reported that over 20 % of inspected PV installations experienced a fire incident in the given year [35]. Both figures are based on non-randomised samples, so generalisation to the broader scope of PV installations is not directly applicable. However, they clearly indicate that fire-related defects of smaller magnitude may be significantly more prevalent than what formal incident statistics, which cover only events attended by firefighters, suggest. This is broadly consistent with the concept of Heinrich's triangle, the established theory of industrial accident prevention concerning the ratios between minor and major accidents, where, in this case, firefighter-attended incidents represent a smaller fraction of all PV-related faults and minor fire events. An

Fig. 2. Accident triangle showing the potential scope of total PV-related fire incidents.

example is shown in Fig. 2, where the top three levels display the approximate ratios from the actual cases in the Swedish dataset considered in this study, the only dataset considered with systematically reported consequences.

This paper analyses PV-related fires requiring firefighter intervention in the UK, Italy, Slovenia, and Sweden. The new findings are compared with the estimated annual frequency of 29 fires per GW of installed capacity reported by Mohd Nizam Ong et al. [36], which, despite the heterogeneous nature of the underlying datasets, remains the most comprehensive quantitative estimate so far. It focuses not only on reported fire frequencies but also on how different national data collection methodologies influence these values. The study aims to provide data on fire occurrence across the four countries, while the Swedish dataset is analysed in greater detail to provide insight into ignition sources and fire consequences. These data can serve as a foundation for risk analysis and risk management concerning rooftop PV systems, as well as provide general guidance for the fire safety of PV systems in general.

2. Methodology

Data on PV-related fires were obtained from official national-level institutions with systems in place to record all such incidents. This is usually managed within the general system, where firefighters submit reports after incidents for which their services are requested. In previous publications [19,20,36], data were not collected systematically but instead required manual search queries and filtering in various media or national databases. For this study, however, two of the four databases (Italian and Slovenian) had already been updated to enable incidents entered into the database to be uniformly labelled as PV-related, allowing for systematic filtering of the data. This step can importantly reduce uncertainties in later stages of data collection process, where manual queries from free text fields are performed to filter out incidents related to PV systems. There remains a possibility of errors in the process

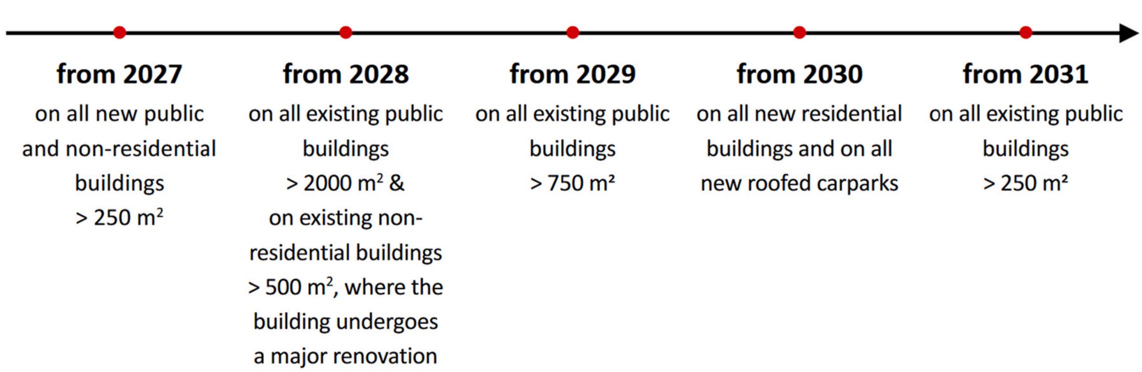

Fig. 1. Timeline with gradually increasing requirements regarding PV installations on buildings in the EU.

of completing the data input forms, as members of fire brigades responsible for these tasks likely faced demanding conditions affecting their physical and mental performance before completing the entries [37]. However, such errors were not considered within the scope of this study. The procedure for obtaining the database in each country is described in more detail in section 2.2.

2.1. Prevalence of PV systems

As in many other countries, the prevalence of solar power systems in the UK, Italy, Slovenia and Sweden has increased in recent years. This is particularly evident in the UK, Italy and Sweden, but the increase is also apparent in Slovenia. However, as shown in Fig. 3, there are significant differences in the capacity and number of PV systems installed across these countries. The Italian data on the number and capacity of the PV systems are based on reports by the Gestore dei Servizi Energetici (GSE) [38], and for 2024, part of the data was obtained from TERNA S.p.A., the grid operator [39]. The Slovenian statistics on the capacity of PV systems installed in Slovenia were obtained from the PV portal [40], managed by the Laboratory of Photovoltaics and Optoelectronics, Faculty of Electrical Engineering, University of Ljubljana [41]. For Sweden, the statistics are provided by the Swedish Energy Agency [42], a government entity to which all PV installations must be reported when connected to the power grid. From 2018 to the year 2024, the total capacity of solar power systems connected to the Swedish power grid increased from 140 MW to almost 4808 MW [6]. Measured by capacity,

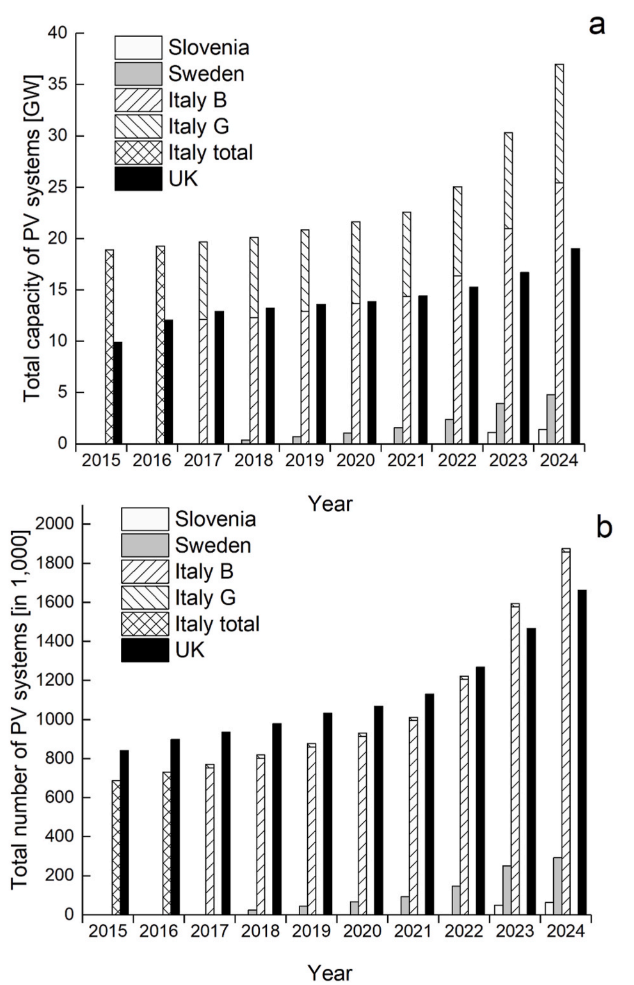

Fig. 3. Total capacity (a) and number of PV systems (b) installed in Italy, Slovenia and Sweden, with data for Italy divided between ground installations and on-building installations from 2017 onwards.

small solar power systems (i.e., those with a capacity below 20 kW) account for about 55-60 % of the total connected capacity of solar power systems over time. The UK figures for the number of installations and their capacity were obtained from data released on 26 March 2026, as an Accredited Official Statistics publication by the Department for Energy Security & Net Zero (DESNZ) [43].

2.2. Fire incident statistics

To improve future risk assessments, a harmonised minimum dataset is needed to ensure comparability between national statistics. Differences among national systems for reporting fire statistics have long been recognised and can hinder direct comparisons between countries. The European Commission has made efforts to address this issue and promote alignment, notably through the recent EUFireStat project, which provided a comprehensive overview of the differences among countries [44] and proposed potential steps to harmonise the various systems. Even when comparing data on PV-related fires, significant differences persist. For example, in Italy, the label for a PV-related fire is "pannelli fotovoltaici", which roughly translates as 'PV module'. This means it is applied only when the PV modules themselves are involved in the fire. Incidents involving other parts of the PV system, such as inverters or cables, are therefore not included in the statistics. Similarly, data for the UK include only incidents with the terms "Solar panel" or "Photovoltaic panel" in the free text field. In contrast, in Slovenia, the label is "sončna elektrarna", which roughly translates as 'solar power plant', and incidents involving any part of the PV system are included, even if only a cable or an inverter at ground level of the building burns, with no involvement of the PV modules. This distinction in the scope of included incidents is visually represented in Fig. 4 as it results in a much broader range of incidents being included in the statistics for Slovenia, compared to Italy. The methodology for data from Sweden is closer in scope to the Slovenian approach, including all parts of PV systems, as opposed to Italy and the UK, where only incidents in which PV modules were affected are counted. It must be noted that, within the scope of this paper, the term "PV-related fire" refers to any incident in which a component of the PV system was involved, regardless of whether the PV system was the ignition source or if the fire originated elsewhere and later spread to the PV system. This broad definition is adopted since firefighters responsible for feeding the data into the national databases are not always capable of distinguishing between these two categories; thus, the term reflects involvement of the PV system in a fire.

2.2.1. Italy

Italian data 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), which gathers reports from all fire brigades. A specific "Photovoltaic Panels" category was introduced in the CNVVF system in 2014 to better capture the phenomenon of PV-related fires. Before 2014, all data had to be manually reviewed by searching the free-text fields of the database using specific keywords such as "photovoltaic fire", "solar panel fire", or similar terms, which could lead to inconsistencies. The Italian data used in one of the aforementioned papers [36] includes data up to 2015. Here, more recent data is considered, including data from 2015 to 2024. The Italian numbers for panel fire events reflect PV-related incidents where the PV module(s) were involved in the fire, irrespective of whether the modules were the ignition source or whether the fire originated elsewhere and subsequently spread to the PV system, a limitation shared with most national fire statistics which have already been discussed previously in Section 2.2. A separate query was conducted on the dataset to obtain the numbers for fires involving PV module(s) only on buildings (excluding ground-mounted, agrivoltaics, floating, etc.), labelled in Table 3 as Italy B(buildings). From the total number and the number for buildings, the number of ground installations was calculated and labelled as Italy G(ground). The distinction between

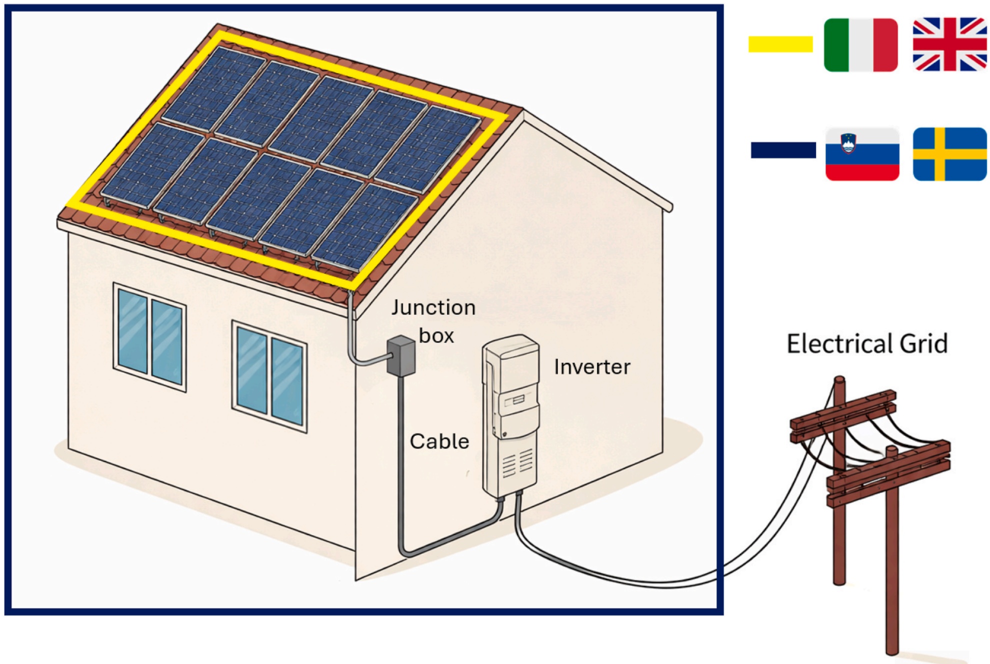

Fig. 4. Scope of incidents included in the databases for each country.

building-mounted and ground-mounted installations is only available from 2017 onwards, due to the availability of the national PV data, which is not related to the fire incident database. Previous reports do not divide the data in this way, making it impossible to calculate the two categories for earlier years.

The Italian dataset identifies incidents through the operational classification “photovoltaic modules involved in the fire”. Therefore, the reported figures should be interpreted as fires involving PV installations rather than confirmed fires originating within the PV system. The operational reporting procedure used by the Italian National Fire Brigade is primarily designed for emergency response documentation and national statistics rather than forensic fire investigation. Consequently, the involvement of PV modules does not by itself establish whether the PV system was the ignition source or whether it was affected by a fire originating elsewhere.

A subset of incidents can be identified where the incident commander classified the origin as an electrical cause. These cases may represent a lower-bound estimate of fires potentially originating within the PV installation. However, this subset should be interpreted with caution because the determination of fire origin is performed under operational conditions, incident commanders have heterogeneous levels of training and experience in fire investigation, and many incidents are ultimately classified as having an undetermined cause. Therefore, the true proportion of fires originating within PV systems is likely to lie between the number of incidents classified as electrical in origin and the total number of incidents involving PV modules.

Although the Italian dataset does not allow a definitive attribution of fire origin to the photovoltaic installation, incidents classified as having clearly identifiable non-electrical causes represent only a minor fraction of the observed cases. Most events are classified either as having an electrical origin or as having an undetermined cause. Consequently, the available evidence does not support the interpretation that the majority of PV-related incidents result from fires clearly originating outside the PV installation. At the same time, the data do not allow a definitive attribution of origin to the PV system itself, highlighting the limitations of operational fire statistics for detailed fire causation analysis.

The distinction between building-mounted and ground-mounted PV installations is only reported from 2017 onwards [38]. This limitation is not related to the Italian fire incident database itself, but rather to the availability of national exposure data. While the annual installed PV capacity was available separately for ground-mounted and non-ground-mounted systems from 2010, the corresponding number of installations in these categories was provided by the Italian Energy Services Operator (GSE) only from 2017 onwards, following a dedicated data request. Consequently, fire frequencies expressed per number of installations could only be calculated separately for building-mounted and ground-mounted systems from 2017 onwards.

Another point to note is that the number of fires recorded for Italy from 2022 to 2024, particularly in 2024, differs from that reported in a previously published paper [45]. After consulting the database administrator, it was found that some submissions had accidently remained open pending a central check in 2025. As a result, after correcting this inconsistency, the numbers for these three years increased. One reason for not finalising the submissions may be that they related to small-scale events for which there was no official request to submit the form, so the inconsistencies were not immediately detected. This leads to delayed submission of the forms and, consequently, changes in the number of fires after the forms are finalised, since the system does not include the numbers from non-submitted forms.

Fig. 5 shows an example of the flowchart for obtaining data from the national database which collects all the Intervention Forms from the entire national territory, except for the autonomous provinces of Aosta, Trento and Bolzano.

2.2.2. Slovenia

Data on fires in Slovenia were obtained from the Slovenian Administration for Civil Protection and Disaster Relief (URSZR) [46]. URSZR is responsible for collecting reports on incidents reported to the emergency number (112) to which the firefighters were deployed. In mid-2023, URSZR updated the reporting system to include a category for PV-related fires, so data for this type of incident was gathered for the period between 30 May 2023 and 19 July 2024. An Excel spreadsheet was obtained from URSZR, with all the entries labelled as PV-related. Since only partial data was available for the two years - a little more than half of the first year and a little more than the first half of the second year - annual totals were estimated by calculating the average weekly incident rate from the available intervals and multiplying it by 52 weeks, assuming that PV-related fires occur with the same frequency

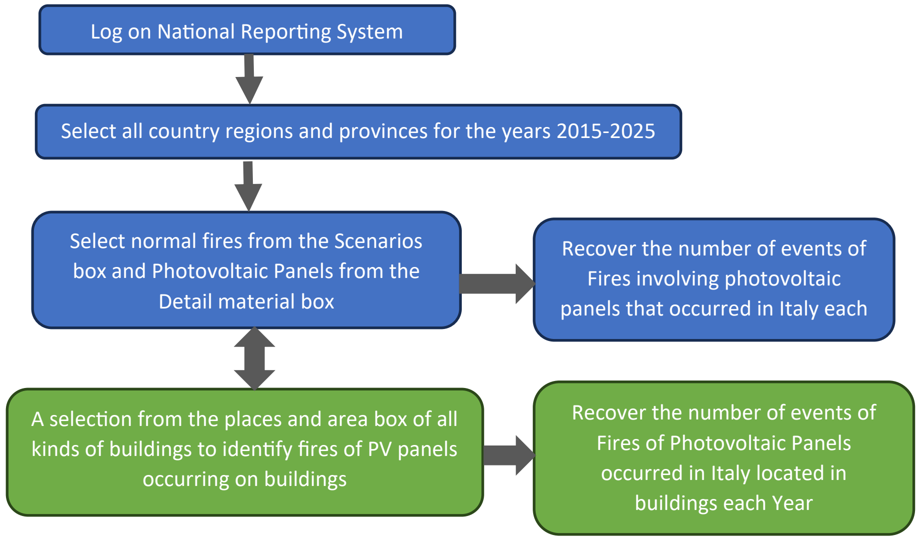

Fig. 5. Flow chart for data collection from the Italian system.

in both halves of the year. Table 1 provides an example of a translated version of a Slovene data output row, stripped of irrelevant data.

2.2.3. Sweden

The Swedish data was obtained from two major Swedish government authorities: the Swedish Civil Defence and Resilience Agency (MCF) and the National Electrical Safety Board (Elsäkerhetsverket). The data comprises of reports from the Swedish fire rescue service, which must be submitted to MCF after each response to a fire or other incident. MCF collects these reports from the fire rescue services. However, fires in solar power systems are not currently a specific category in the reporting template. Therefore, the National Electrical Safety Board has collected the incident data from MCF and post-processed it in order to identify which fires are considered to be caused by equipment related to solar power systems. The data was received as raw data in an Excel spreadsheet. Table 2 provides an example of a translated version of a Swedish data output row that has been stripped of irrelevant information.

Within the Swedish dataset received, the National Electrical Safety Board added an additional judgement on whether the fire started in, or involved, PV system equipment. This judgement is based on the description of the cause and incident, provided by the incident commander in the reporting template. The data was cross-checked by the authors and an additional researcher to ensure correct labelling. Furthermore, the Swedish data was reviewed for the extent of damage caused by the fire, derived from the incident description given by the incident commander. The extent of fire damage was categorised into six categories, as follows:

- Damage to PV equipment indoors
- Damage to PV equipment outdoors
- Damage to PV equipment and adjacent surfaces indoors
- Damage to PV equipment and adjacent surfaces outdoors
- Fire spread inside the building
- Building completely damaged by the fire

In most cases, categorisation was relatively straightforward. However, in some cases, the researchers discussed the probable extent of fire damage based on the incident description. If no consensus was reached, a third person was consulted.

2.2.4. The UK

Data for the UK are obtained from a release by the Department for Energy Security & Net Zero (DESNZ) [47], which includes data collected through a manual search to extract fire incidents where the terms “solar panel” or “photovoltaic panel” appear in the additional information free text. Therefore, fires involving any other parts of PV systems (such as connectors, cables and inverters) are not included in the statistics. Incidents where different terms are used to describe solar or photovoltaic panels, such as ‘solar module’, ‘PV module’, or ‘PV panel’, are also excluded from the statistics. According to some reports, not all national fire services were able to provide the data [48], so the actual number of PV-related fires in the UK might be even higher. But there are already some active initiatives [49], focusing on tackling this issue while also incentivising report collection for smaller cases that usually do not reach the fire service, aiming to properly collect input data for the lowest level of Heinrich's triangle, as shown in Fig. 2.

3. Analysis

In this section, the statistical data from the different countries are analysed.

3.1. Fire occurrence in PV systems

The number of PV-related fires in each of the studied countries is shown in Table 3. As the data indicate, the general trend in all countries is an increase in PV-related fires. The number of fires generally corresponds to the rise in the number of installed PV systems and capacity. Previous research from Germany has suggested that many fires occur in

Table 1
Example of a data output row from the Slovene database. Translated and stripped of irrelevant data.

PKID	Time of report	Year	Time of origin	Event group	Event	Type of Object	Object	Quantity	Type of damage	Solar power plant
348457	30.05.2023 13:04	2023	30.05.2023 13:01	Fires in buildings	Complex industrial facilities	Administrative and office buildings	Business premises	1	Damaged/ flooded	TRUE

Table 2
Example of a data output row from the Swedish database. Translated and stripped of irrelevant data.

Rescue service	Time & Date	Incident	Building use	Room of ignition	Object of ignition	Cause of fire	Description of cause	Description of incident
RSGBG	14:05:39 2023-05-09	Fire or fire in a building	Commercial	Electrical room	Cable	Fault in equipment	Store staff notices smell of smoke from the electrical room. When they open the door, they see smoke from the electrical central equipment.	1530//Meet up with staff on site. Staff from store.//They show us the electrical room. We check it with a thermal imaging camera, but can't see anything unusual. The fuses for the solar power system have been triggered.

Table 3
Number of PV-related fires for all four countries, with data for Italy further divided between installations on buildings (Italy B) and ground installations (Italy G).

Year	Italy	Italy B	Italy G	Slovenia	Sweden	UK
2015	97	85	12	-	-	21
2016	139	124	15	-	-	30
2017	152	146	6	-	-	31
2018	186	175	11	-	8	27
2019	203	189	14	-	7	26
2020	181	167	14	-	12	39
2021	191	182	9	-	15	64
2022	297	290	7	-	16	43
2023	382	364	18	44	42	68
2024	401	364	37	49	55	81

the first year or years of a system's lifespan due to poor installation quality [19], but the age of the affected PV systems could not be assessed with the data available for the four countries in question. Some caution is still required when directly comparing numbers between datasets, as data collection methodologies vary among datasets. The data for Germany available in the mentioned reference was not included in the scope of this study for several reasons: the available timeframe overlaps poorly with the datasets considered here, the incidents were not collected in a systematic manner (online survey), and the resulting differences in methodology would further complicate comparison with the four countries studied.

The number of fire incidents can be expressed in several ways. The fire occurrence rate has previously been estimated at 28.9 fires per GW per year [36]. Another source estimates the likelihood at approximately one fire per 10,000 installations [50]. Fig. 6 shows the number of fires per installed GW for the four countries in question. The Swedish and Italian data show a high correlation, with a slightly lower number for the UK, while the Slovenian data are higher. Although the Slovenian numbers are higher, all figures remain within the same order of magnitude. It should also be noted that, according to descriptions of national methodologies, significant variation exists between the scope of events included in each dataset, and thus, the numbers are not directly comparable as indicators of safety levels.

Examining the number of PV fires per 100,000 installations, a similar pattern is evident in Fig. 7. The Swedish and total Italian data show similar numbers, with approximately 10-20 fires per 100,000 installations on average. The UK figure is slightly lower, at around 5, while Slovenian data indicate higher numbers, around 80. Notably, Sweden had more fires per installed GW than Italy in 2019, 2020, and 2021; however, when expressed as fires per 100,000 installations, Italy experienced more fires during these years. Again, as with the capacity-based metric, these values reflect both the incident occurrence as well as the differences in the reporting scope.

Furthermore, for the Swedish data, the statistics differ depending on system capacity. In Table 4, the fire incidents per year and 100,000 systems have been calculated depending on capacity. Here, it should be noted that the incident reports do not include capacity, so it is based on an assumption of the building type associated with different capacity systems. For systems <20 kW, single-family houses and garage buildings have been included, while systems >1000 kW have been assumed only to be "solar power parks". For 20 – 1000 kW systems, all other building types have been included. Since such a division of system capacity data is not available for the other countries considered, further analysis is limited to the Swedish dataset, which restricts the generalisability of the findings to some extent. Additionally, the analysis does not distinguish between different PV system typologies, such as building-integrated PV

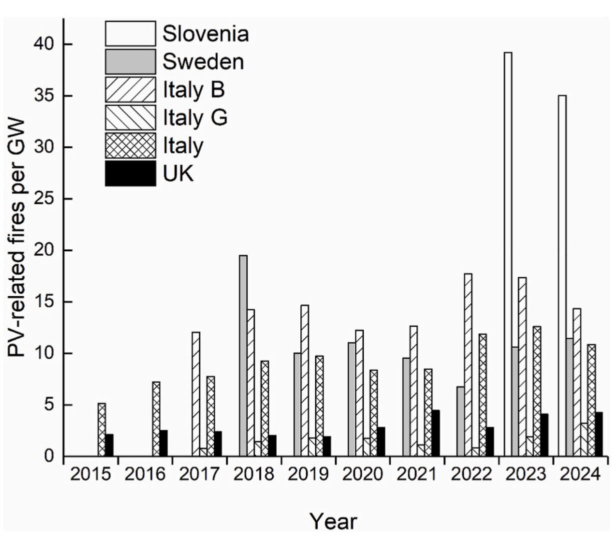

Fig. 6. The number of PV-related fires per gigawatt of installed capacity in the UK, Italy, Slovenia and Sweden, with data for Italy also shown separately for ground (G) and on-building installations (B) from 2017 onwards.

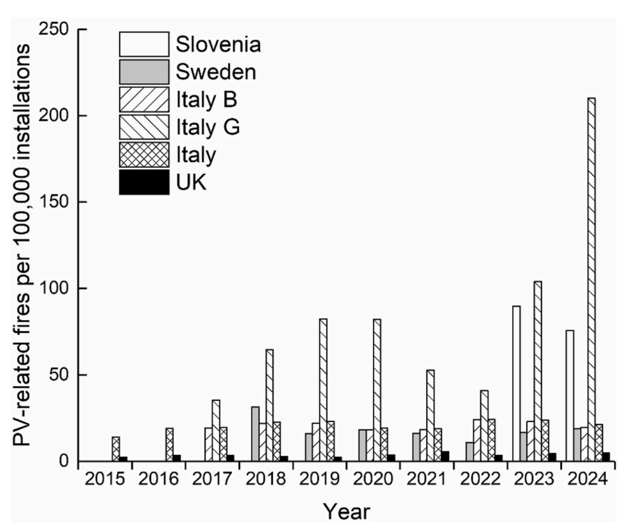

Fig. 7. The number of PV-related fires per 100,000 installations in the UK, Italy, Slovenia and Sweden, with data for Italy divided between ground installations (G) and on-building installations (B) from 2017 onwards.

Table 4
Number of fires per 100,000 systems in Sweden, depending on system capacity.

Year	<20 kW	20 kW – 1000 kW	>1000 kW	Total
2018	23	76	0	31
2019	3	96	0	16
2020	7	77	4545	18
2021	10	58	0	16
2022	5	49	1587	11
2023	13	47	1010	17
2024	8	103	3846	19
Average	10	72	1570	18

(BIPV), building-applied PV (BAPV), grid-connected, and off-grid systems, as this information is not systematically collected in the national databases.

As the data in Table 4 show, there are major differences in fire prevalence depending on system capacity. For small systems, the assumption of ten fires per 100,000 systems seems to be fairly accurate, but for larger systems, it provides a vast underestimation of the number of fires. It should be noted that even though 90 % of the systems connected to the Swedish power grid are small systems, these sorts of systems are only responsible for approximately 49 % of the fire incidents.

If the number of fires is instead expressed per GW connected to the Swedish power grid, the difference between system capacities is smaller; see Table 5. However, there remains a considerable difference between large and small systems, potentially indicating that large systems might have a significantly lower risk per GW connected to the power grid than small systems. Furthermore, it should be noted that the number of fires for large systems (>1000 kW) is small and thus, a single fire incident impacts the statistics significantly. Due to this, the numbers for large systems are associated with considerable variability.

3.2. Object of fire origin for PV systems

Within the Swedish data, the object of origin for the fires in the solar power systems was identified by the National Electrical Safety Board through the incident reports from the fire rescue services, see Fig. 8. The most common cause of ignition was found to be DC cables and/or connectors, which accounted for about 25 % of the fires. This is consistent with findings from other PV failure and risk analyses, which identify connectors and DC cabling as among the most failure-prone components due to installation errors, mechanical and material degradation that can lead to heating, arcing and ignition [34,51]. DC cables and connectors were followed by DC switches, such as the “fire rescue service switch”, and the electrical central unit on the AC side, which both accounted for about 20 % of the fires. The fire rescue service switch is a common fire protection addition to solar power systems in Sweden, intended to minimise the lengths of DC cables carrying current during a fire. However, the risks associated with such switches have recently been discussed, as several fire incidents in which these switches were the cause of ignition have been reported. This problem is confirmed by the recent statistics [52].

As shown in Fig. 8, the solar panels and the converters are the least common objects of ignition. However, when assessing the statistics, it should be noted that the number of fires is still limited, and looking at different years individually affects the proportions of the object of origin vastly. For example, 18 of the fires in the electrical central unit on the AC side were reported in 2024, accounting for approximately 33 % of the PV fires in Sweden during that year.

Italian data allows for a distinction between the cases where the cause of the fire is in the report form recognised by the team leader as “electric cause”. This information could be interpreted as the cases where the PV system was the origin of the fire, compared to the others, where the PV system might be labelled as the victim of a fire originating elsewhere. Since there is no special training or requirement for the team leaders to obtain knowledge about forensic investigations of root causes of fire, this data was not specially presented.

Table 5
Number of fires per GW connected to the power grid in Sweden, depending on system capacity.

Year	<20 kW	20 kW – 1000 kW	>1000 kW	In total
2018	26.5	14.7	0.0	19.5
2019	2.9	18.1	0.0	10.0
2020	7.4	14.3	18.9	11.0
2021	10.1	10.4	0.0	9.5
2022	5.2	9.0	7.0	6.7
2023	12.5	8.4	3.8	10.6
2024	7.5	17.7	13.2	11.4
Average	10.3	13.2	6.1	11.3

3.3. Consequences of fires in PV systems

Within the Swedish data, the fire extent could be derived from the incident reports from the fire rescue service as described in Section 2.2.3. The extent of the fires is shown in Fig. 9. As the figure shows, the most common fire extent is damage only to PV equipment outside, accounting for approximately 36 % of the fires. This is typically fire damage to cables, connectors, panels and/or converters located outside the building. The second most common extent is damage only to PV equipment indoors, accounting for about 32 % of the fires. This is commonly damage to the electrical central unit or connectors/cables on the inside. Thus, in total, fires with only local fire damage to PV equipment, either inside or outside accounts for approximately 68 % of the fires in solar power systems.

Fires spreading to adjacent surfaces outdoors account for about 13 % of the fires. In general, this is fires where the fire has started in a solar panel or converter and caused damage to the adjacent roof or façade. The damage is typically limited to the area adjacent to the equipment, but in some cases, large roof areas have been affected. Similarly, for fire spread to adjacent surfaces indoors, which account for about 11 % of the fires, the fire damage is typically on the wall or roof surfaces adjacent to the PV equipment. In about 5 % of the fires, the fire will spread to several rooms or to the roof construction inside the building. In these cases, the extent of fire damage is significantly larger than when restricted to equipment and adjacent surfaces. In many cases, the fire spread to non-accessible areas in the roof construction or similar, which meant that the fire rescue service was forced to demolish parts of the construction to reach the fire.

Fires where the building was completely destroyed by the fire account for about 3 % of the fires, or five fires in total during the examined time frame. Notably, in four of these cases, the buildings were barns or animal stables, and in the last case, it was an uninhabited summer house.

3.4. Fire risk for the buildings with PV installations

Risk is typically defined as the product of the probability of an unwanted event and the extent of its negative consequences [53]. In quantitative risk assessment, a commonly cited tolerable level for individual detrimental risk is of the order of 10^{-6} [54], corresponding to one fatality per million people annually. While such a benchmark can provide useful context, directly equating building-related losses with fatalities should be approached with caution. With the available Swedish data, where fire consequences were also evaluated on a scale, it is now possible to quantify the risk in the context of PV systems for the first time. Reinterpreting the risk in the context of PV systems as the probability of a PV-related fire multiplied by the building's vulnerability, which can be considered a proxy for consequences, allows for this quantification. The probability of a fire occurring in a given year can be calculated by dividing the number of fires by the total number of installations, or by the installed capacity if more appropriate. The negative consequence of a significant loss is indicated by 8 % of fire cases

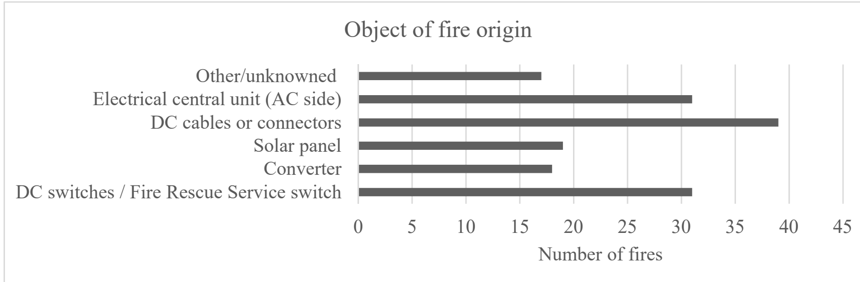

Fig. 8. Object of fire origin for Swedish PV system fires during the full study period, expressed as absolute counts.

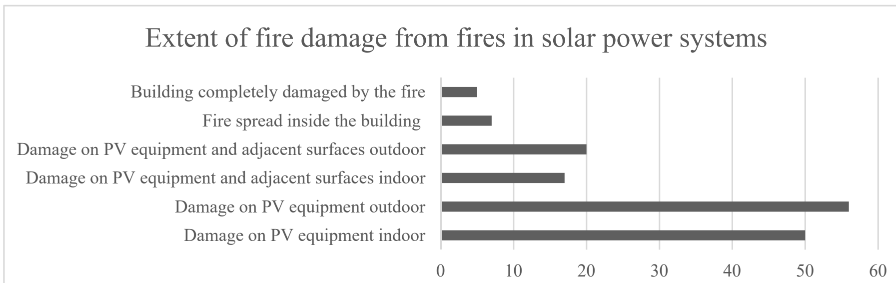

Fig. 9. Extent of fire damage for Swedish PV system fires during the full observed period, expressed as absolute counts.

resulting in significant flame spread. Using data from Sweden for 2024, the risk of a significant loss in buildings with installed PV systems is 1.37 x 10^{-5}. This value should be interpreted as an empirical approximation based on available Swedish data. The value represents a preliminary and approximate reference since it is derived from a single national dataset and relies on simplified assumptions regarding consequence quantification. Direct comparability with formally established risk benchmarks and generalisability to other national contexts would require a broader dataset obtained through a harmonised methodology.

4. Discussion

When interpreting the presented PV fire incident data, it is important to note that this study includes data from four countries, but the depth of analysis varies considerably between them due to differences in data availability and collection practices, rather than a deliberate analytical choice. Swedish data included the most information; in addition to the number of fires and installations, as well as their total capacity, which was available for all countries, it also contained information on fire sources, consequences of the fires, and system capacity. Due to the availability of this data, Sweden can effectively be considered the reference case for all these parameters. Data from Italy, Slovenia, and the UK primarily contributed to the fire-frequency comparison and the discussion of reporting methodologies.

The primary factor limiting the direct cross-comparison of data between countries is the difference in reporting methodology. Examining Slovenian figures might suggest that fire safety levels in PV systems are lowest there, but a closer look at the data collection methods shows that Slovenia is one of only two countries already conducting systematic data collection, unlike the manual search queries used in the UK and Sweden. Compared with the Italian system, the Slovenian system covers a broader range of incidents, including all fire incidents involving any part of the PV system, whereas the Italian system includes only fires in which PV modules were involved. Conversely, the figures for the UK, which are the lowest in the set, are likely underestimated, as they were obtained through a text search query and include only incidents where modules were involved in the fires. Despite significant differences in collection and classification methodologies, the fire frequencies derived from the analysed national datasets consistently remain within the same order of magnitude over several years of observation. This finding suggests that the overall level of PV-related fire occurrence may be more robust to differences in reporting methodologies than might initially be expected.

The reliance on incident reports imposes several limitations and challenges. Firstly, fires that are not reported to the fire rescue service are excluded from the datasets. There are probably several fires that, for some reason, are not reported in the national fire statistics. For context, the Swedish Fire Safety Association estimates that 70 % of residential fires go unreported annually [55]. Another report from a US-based company managing solar assets for various clients stated that, in the portfolio they managed, they observed fires at 21 % of sites equipped with drones for continuous inspections in 2025 [35]. This suggests that the actual number of fires is probably much higher than those requiring firefighter intervention, as illustrated in Fig. 1. However, most of these fires likely remain small and have limited consequences for the PV system and/or the building.

Regarding the cause of the fire, in the Swedish data, incident reports do not list solar power as a standard cause. Most fires are instead categorised as “fault in equipment” or “not possible to tell”. The data was extracted by the Swedish Civil Defence and Resilience Agency and reviewed by the National Electrical Safety Board, which conducted thorough searches for references to solar power equipment in the reports. However, some incident reports may have used different terminology or labelling, making it more difficult to identify these fires. This is probably a limited issue, but the exact extent to which data is hidden or missed cannot be predicted. Similarly, in Italy, there is no specific option, but team leaders responsible for completing the forms after incidents sometimes select “electrical cause”, which can be interpreted as the fire starting in the PV system, while incidents not classified as having an electrical cause may include both externally initiated fires and fires for which the origin could not be reliably determined during emergency response operations. The datasets provided for Slovenia and the UK did not include any information on potential ignition sources that started the fire. Furthermore, fire incident reports are inherently based on the subjective experience of the incident commander. Thus, the data is limited by the perception of that commander, and also by their ability to describe the incident. This could mean that some of the fires, and/or fire development and cause, have a flawed or faulty description. In such cases, the incident could be mislabelled or overlooked. As the assessment on probable cause and extent of fire damage is based on Swedish incident reports, there is an additional possible cause of error in the reading and understanding of the reports.

In cases with limited fire damage, the object ignition is often easy to identify, since it is mainly that object that is damaged. However, in cases with extensive fire damage, the object of ignition can be more difficult to assess. Thus, larger fires are associated with more uncertainty in the assessment. Several fires in which the building burned down completely were not included in the data, since the cause of the fire could not be linked to the solar power system in the building.

With regard to the Italian dataset and frequency of fires in relation to the number of plants or installed power, although it does not provide direct forensic evidence regarding the origin of individual fires, the predominance of incidents classified as having either an electrical or an undetermined cause is consistent with the fire frequency commonly reported in the literature for PV systems, related to insulation failures, earth faults and DC arcing phenomena. Furthermore, operational experience accumulated through emergency response and fire investigation activities suggests, in term of expert judgement, that rooftop PV installations are largely more frequently involved as potential ignition sources than as passive victims of fires originating elsewhere. However, this interpretation should be regarded as supporting context rather than a conclusion directly demonstrated by the statistical dataset.

Keeping in mind the limitations imposed by non-harmonised data collection methods, which hinder direct cross-country comparison as previously discussed, this paper contributes to the ongoing effort to quantify fire risk in PV systems. It combines frequency and consequence data for the Swedish case, enabling quantification of the risk of significant loss of a building with a PV system installed, and finds that this risk is not negligible. The overall numbers for extensive fire spread and total destruction of the building are also in a similar range to the older data from a German report [19], where the consequence categories are defined slightly differently, but in that dataset, 6 % of cases led to a total destruction of the building, and in addition to that, fire spread outside of its origin in 32 % of fires. It is also important to note that the Swedish frequency fits fairly well with Italian and Slovenian data. The first term in the described risk equation reflects more the factors related directly to the PV system, like component quality, installation practices and maintenance, while the second term depends more on the PV system configuration, susceptibility of the building to the ignition and fire spread, depending heavily on architectural design and materials' performance in fire. In this sense, the second term of the equation can be deemed as a vulnerability of the building. At this point, it is also worth noting that the building vulnerability is oftentimes determined by pre-existing conditions, since most of the buildings equipped with PV systems were built years ago, with no PV installation in mind.

For improved risk assessment in the future, PV-related fire reporting should adopt a more harmonised approach with a minimum set of variables and information. Expansion of the existing reporting systems established for the firefighters seems currently the best approach. Data collection could be divided into the incident level, where reports would record whether a PV system was present at the site, whether it was involved in the fire, and whether it was the source of the fire or merely affected by it. Another level could be the system level, where data would include installation type (building-applied or building-integrated), position of the installation (roof, façade, balcony, ground-mounted etc.), age of the system, system capacity, and the presence of potential safety devices or systems. At the aftermath level, the consequences of the incident should be recorded in terms of the extent of fire spread, damage to the building, and any injuries or fatalities. With such data collected in a more harmonised manner, more comparable metrics between different countries could be derived.

5. Conclusions

Reported PV-related fire statistics vary significantly due to differences in national data collection methodologies, limiting direct cross-country comparability. This study analysed fire incident data from the UK, Italy, Slovenia, and Sweden for the period from 2015 to 2024 to quantify fire frequency, identify ignition sources and assess fire consequences from available data obtained for each country. The reported numbers of fires per GW of installed capacity of PV systems range from about 5 to 13 annual fires for Italy, 7 to 19 annual fires per GW in Sweden, 2 to 4 fires per GW in the UK, and about 35 to 40 fires per GW in Slovenia. The numbers for annual fires per 100,000 systems are below 5 for the UK, between 14 and 24 in Italy, between 11 and 31 in Sweden, and about 80 in Slovenia. Differences in these numbers are likely driven primarily by methodological differences in data collection rather than actual fire safety levels. The Slovenian and Swedish datasets include a broader range of events compared to the Italian one, and the UK figures are based on a text search query, so both likely underestimate the true number of incidents.

Comparing system sizes within the Swedish dataset, small systems (<20 kW) have significantly lower fire occurrence per 100,000 systems, with an average of ten fires per year in Sweden. Medium-sized systems (20 – 1000 kW) have an average of 72 fires per 100,000 systems, and large systems (>1000 kW) have an average of 1570 fires per 100,000 systems. When the number of fires is expressed per GW of installed capacity, the differences between size categories are smaller, with averages of approximately 10, 13, and 6 fires per GW for small, medium, and large systems, respectively.

In the Swedish dataset, DC cables and connectors are the most frequently identified objects of ignition, accounting for approximately 25 % of cases, which is also consistent with broader PV failure literature. This is followed by the electrical central unit on the AC side, along with DC switches, which combined account for approximately 20 % of fires. Fires with solar panels and converters as the object of ignition are also reported, but less frequently. However, the data is limited, and the objects of ignition vary quite significantly from year to year in the data, so these proportions should be interpreted with caution.

Regarding the consequences, the extent of damage in PV-related fires in the Swedish dataset varies, but most fires (68 %) stay limited to PV equipment, either inside or outside the building. In 24 % of cases, surfaces around the equipment have been damaged, and in about 8 %, significant fire spread was observed. Dividing this further, about 3 % of fires resulted in a total loss of the building. Based on the Swedish data gathered and analysed in this study, the first preliminary fire risk assessment for buildings equipped with PV systems was determined to be approximately 1.37×10^{-5}. This value is not negligible, and some currently available evidence already suggests that unaccounted incidents could raise this number even higher. However, it must be emphasised that the value is based on a single national dataset, relying on some simplified assumptions, so it is not directly generalisable to wider contexts without further data and analysis.

A significant challenge for this study was the lack of harmonisation across national fire reporting systems, which prevented direct cross-country comparisons. Additional challenges included smaller fires that are not included in the datasets because firefighters are not alerted, and difficulty in determining whether the PV system was the cause or merely a victim of the fire. Addressing these limitations would require implementing a harmonised minimum reporting dataset across countries, capturing not only the involvement of the PV system in the fire but also whether ignition started within the PV system, as well as details about its age, size, and the extent of damage caused by the fire. Unified data would help confirm research findings and provide data-based evidence for fire safety regulation and risk management of PV systems internationally.

CRediT authorship contribution statement

Nik Rus: Conceptualization, Data curation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Axel Mossberg:** Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Vincenzo Puccia:** Resources, Writing – review & editing. **Cecilia Wetterqvist:** Resources. **Aleš Jug:** Resources. **Grunde Jomaas:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

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

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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