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Research papers

Quantitative fire likelihood assessment of battery home storage systems in comparison to general house fires in Germany and other battery related fires

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ABSTRACT

Battery storage systems are becoming an integral part of the energy transition by enabling energy availability during periods of low renewable energy generation and by providing various grid services. Currently, the most battery storage systems are deployed in home storage systems (HSSs) and electric vehicles (EVs), and their growth continues exponentially. However, despite this upside development, there are public concerns about potential fire risks associated with photovoltaic (PV) home storage systems and EVs. This paper presents a quantitative analysis comparing statistics of fires occurring in HSS with fires in PV systems, in EV, internal combustion engine (ICE) vehicles and, general house fires. However, because of a lack of available data, HSS fire incidents in Germany for 2023 were determined through web crawling, while other probabilities were derived from already existing research data. The results show a significantly lower probability of an HSS fire compared with a general house fire. In detail, the findings indicate that the probability of an HSS fire is very low (0.005 %) and is 50 times lower than for a general house fire. All home appliances have a generally low probability of catching fire, which is also true for HSS. If compared to other home appliances, HSS share roughly the same probability of catching fire as tumble dryers. Furthermore, compared with the fire probability of HSS, PV systems demonstrate an even lower probability, approximately three times lower than that of HSS. The probability of a traditional ICE vehicle fire (0.089 %) is approximately four times higher than that of an EV fire. The probability of an HSS catching fire is approximately 18 times lower than an ICE catching fire and four times lower vs. an EV. These findings provide important insights into the risks and safety aspects of battery storage in the residential buildings, thus supporting to make informed decisions about integrating of renewable energy systems.

1. Introduction

To combat climate change and achieve its emission goals, Germany enacted the Climate Protection Act (KSG; Klimaschutzgesetz) targeting a 65 % reduction in greenhouse gas emissions by 2030 compared with 1990 levels. These targets require significant reductions in the building and transportation sector [1].

As a result, the demand for electric vehicles (EVs) and battery storage systems that are coupled with a photovoltaic (PV) system (home storage system = HSS) is increasing in Germany. For example, as of October 1, 2023, there were already 1.3 million battery electric cars and more than 900,000 plug-in-hybrids on the roads in Germany, thus recording a 50 % year-to-year-increase [1]. This growth is similar for HSSs. In July 2024, there are more than 1.4 million HSSs in Germany. Compared to the previous year, this number has roughly doubled. The capacity of German HSSs amounts to 12.4 GWh with an available power capacity of 7.9 GW [2,3]. Consequently, HSS enhance the degree of self-sufficiency and the self-consumption of a house with electrical energy [4].

Despite this rapid increase in the number of EVs and HSSs, many Germans have concerns about the safety of this recent technology.

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According to a study by DEVK-insurance, 49 % of respondents believe that EVs have a higher fire risk than cars with internal combustion engines (ICE). Among the over 55-year-olds, as many as 55 % think that EVs are more likely to catch fire. Cars with combustion engines, on the other hand, are only considered a fire risk by 10 % of respondents [5]. Another survey shows that more than half of respondents have concerns about the fire risk of HSS. Just over half of those surveyed also stated that an explosion poses a risk with HSS. However, the technology is generally accepted and 85 % of respondents were somewhat or very positive about its technology acceptance [6].

Popular science articles also give the impression that battery storage systems have safety gaps. Recently, there have been more and more reports of fires and explosions caused by HSS. In October 2023, PV Magazine reported on an incident in which a 30 kWh 'Do it yourself' battery storage system exploded and destroyed an entire residential building [7]. Several cases were also reported in Germany and Austria at the end of September 2023. The amount of damage varies per incident [8]. Various manufacturers are facing those issues and are reacting to the fire incidents. For example, one manufacturer has put some of its HSS into a conditioning mode with a maximum available storage capacity of 70 %. Customers are also being offered the option of replacing the battery storage systems with comparatively safer lithium iron phosphate (LFP) battery chemistry storage systems [9]. Another manufacturer has introduced a replacement program for certain HSS batteries that can overheat and catch fire [10].

Several studies have investigated the failure mechanisms and causes of fires in lithium-ion batteries under various operating conditions [11–13]. Explosion hazards resulting from thermal runaway propagation have also been widely examined [14–17].

A previous study conducted in 2019 by Fraunhofer ISE [18] provides limited insights into the fire risk of PV-connected HSS in Germany, reporting 10 fire incidents among 130,000 registered systems. These findings were based on data from media reports, police and fire department records, and insurance company information. However, given the substantial increase in the number of HSS in Germany in recent years, as well as advancements in battery chemistry that have improved safety, there is a significant research gap in the quantitative fire risk assessment studies focused on HSS and an updated study is necessary. Furthermore, the increasing adoption of PV systems, HSS, and EVs in German households highlights the need for a comprehensive quantitative fire risk study comparing the risks associated with these technologies while also comparing them with general house fires.

As the safety of technology is particularly important at the consumer level, the main goal of this paper is to quantitatively assess and compare the probability of fires occurring in HSS with other common fire incidents, such as fires in PV systems, EVs, ICE vehicles, general house fires, and household appliances. The determined probabilities help to assess the probability of EV or HSS fires. In addition to the statistical analysis, the findings of this study also have important practical implications. Given the low probability of fire incidents in HSS, this research can help increase public confidence in the safety of these technologies and promote more informed decision-making. Policymakers could use these findings as a foundation for developing fire safety regulations and standards tailored to renewable energy systems, ensuring that adequate safety measures are in place.

Furthermore, this study highlights the absence and necessity of a common, publicly available database on fire risks associated with home storage systems. By demonstrating the value of such data, we hope to encourage policymakers to establish such a database, which could serve as a critical resource for future safety improvements, battery design considerations, and overall energy system integration.

2. Methodology

In the following, the methodologies behind calculation of fire probabilities of HSS, PV systems, EVs, and general house fires are explained. We also look at large storage systems, as some data is available for these systems, and therefore include them in our comparison. For HSS, the data was generated by web crawling (see below) because no other data was available. The data required to calculate all other fire probabilities were collected from various literature sources. It is also important to note that the term 'fire risk' specifically refers to the probability or likelihood of fire occurrence in this study. Quantitative assessment of the severity of fire incidents is out of scope of this study, but it is qualitatively discussed in the Discussion and limitations section.

In the first step, the number of general residential fires in Germany is identified. As there is no database for this, the number of fires is determined using two independent estimation procedures. For reference these two methods are also presented in detail in a flow chart diagram in Appendix B. In the first approach, the database for residential fires in the state of North Rhine Westphalia (NRW) is used for 2021 as the most populous state [19]. Then the fire incidents are extrapolated based on the number of residential buildings in NRW and Germany. For the second approach, the number of fires in Germany in 2020 in general is used. As the proportion of residential fires in Germany is not known, this proportion is derived from other European countries. The proportion of residential fires is known in 19 European countries [20]. The mean value of these serves as the basis for the calculation for Germany. Once the number of fires in residential buildings in Germany has been determined for both approaches, the mean value of both approaches is calculated. The fire probability for a residential fire per year is then calculated using the total number of residential buildings in Germany.

To determine the details of the residential fires, the causes of these fires are examined. The causes of fires are broken down by percentage from 2002 to 2022 [21]. This publication looks specifically at electrical fires and provides a more detailed breakdown of their causes [22]. The fire probabilities for electronic appliances, including cooling units and tumble dryers, are calculated as a comparative value. The methodology used is the same for both appliance categories [22]. In a further step, the general number of appliances in the corresponding category in Germany is calculated. The percentage of households in Germany that own the corresponding electrical appliance is known [23]. The number of households in Germany thus results in the number of the corresponding electrical devices per category [24]. The probability of fire per year is then calculated by dividing the number of fires in the electrical appliance category by the total number in the device category.

After probability of residential or house fires, PV-, EV- and HSS-related fires are assessed. While these are not part of general house fires, they are house-experienced fires. For PV-related fires, data is only available from Fraunhofer ISE from 2013 for the German market [25]. Here, PV-related fire incidents between 1995 and 2012 are investigated based on literature research and filled-out questionnaires by technical experts. In addition to several fires caused purely by PV systems, component-level investigation is also presented. Therefore, using this comprehensive study as a basis for calculations, the annual fire risk of PV systems per MW installed capacity is calculated. Assuming a linear relationship between PV system size and fire risk, this study further calculates the probability of PV-triggered fire for an average German household. The methodology of PV fire probability is presented in a flow chart diagram in Appendix C.

Building upon this foundational study [25], a subsequent investigation by Mohd et al. presents a systematic fault tree analysis of reported PV-triggered fire incidents in Germany and several other countries [26]. Therefore, it is also used in this study to get insights into the component-level breakdown of fire causes.

Similar to PV, no credible publicly available study on EV-related fires focused on the German market is available in literature. Multiple studies have been carried out in countries with higher electric vehicle market share, such as *Norway, Denmark, Netherlands, Finland and Sweden*. Even though discrepancies in the data quality and sampling methods exist in these sources, Mohd and Martín-Gómez present a very comprehensive fire risk assessment of these studies, using fault tree analysis [27]. As

Germany has similar vehicle regulations, standards, weather conditions, and driving behavior, the weighted average of EV fire risk in these countries is considered for Germany. The methodology of EV fire probability is presented in a flow chart diagram in Appendix C. The authors are aware that there are also studies and data on EV fires from the UK, USA, and Australia, e.g. [28,29]. For clarity reasons, we choose not to merge different data sources for EV-fires, since the primary goal of this study is to evaluate the fire risk of HSS and set it into context with other daily-life appliances.

In addition, the fire probability of EVs is compared with that of ICE vehicles and plug-in-hybrid vehicles. For ICE vehicle fires in Germany, a report from Meißner is used [30]. On the other hand, for plug-in hybrid vehicles, Sundin compares the fire probability of different vehicle types per 100,000 vehicles in Norway [31]. For Germany, there are only data for fires involving ICE vehicles. These were used to determine the probability of an ICE fire.

The fire probability of large-scale battery storage systems is considered as a further category. The risk of fire in large-scale battery storage systems has been tracked and recorded in a database since 2015 [32]. To compare this data with fire incidents in EVs and HSSs, it's necessary to convert the total number of incidents to a relative number of incidents per capacity per year. To do this, additional sources are used to get the globally installed power and energy capacity per year [33,34]. The total fire probability for each year is then calculated by dividing the number of incidents for that year by the cumulative installed energy capacity for the same year. Finally, the numbers from 2015 to 2023 are averaged, achieving the total fire probability of large-scale battery storage systems.

The methodology of HSS fire probability is presented in a flow chart diagram in Fig. 1. Scientific data on fire incidents involving HSSs is currently unavailable. Nonetheless, recognizing the growing public awareness and concern surrounding HSS fires, in this study web crawlers, specifically Talkwalker and Neticle/Youscan [35–37], are employed to gather relevant information from local press or fire department reports available online. The detailed search strings used in this study can be found in Appendix B. Subsequently, these search strings are applied in a manual search process.

To ensure the reliability of the identified incidents, each found report undergoes a validation process by cross-referencing with independent sources, such as different news items. Additionally, a meticulous verification is conducted for each case to ascertain that the fire was caused by HSS. Fire incidents of Do-It-Yourself HSS and with indication that the PV system caused the fire are omitted. As an extra layer of validation, 20 rural and urban fire departments in Germany have been contacted, confirming the absence of indications suggesting a significant number of unreported cases.

3. Results

3.1. *Probability of general house fires*

The number of fires is determined by using two independent methods. The extrapolation of the fire incidents for NRW to entire Germany in 2022 results in a total of 59,956 fires (see Table 2). Table 1 lists the proportion of fires in 19 European countries that occurred in houses.

As this statistic does not exist for Germany, the average value for the 19 countries is calculated, resulting in a value of 21.34 %, which is close to the numbers for the neighboring countries of Belgium, Poland, France, Denmark and the Czech Republic. For Germany, only the total number of fires for 2020 is known. In 2020, the fire departments in Germany were called out to a total of 230,000 fires [11]. Multiplying the total number by the mean value of the proportions from Table 1 results in a number of 49,082 fires in residential buildings in Germany in 2020. The mean value is then calculated from the two independent methods, resulting in a total of 54,519 fires in residential buildings. Formula (1) is then used to calculate the probability of residential fire per year.

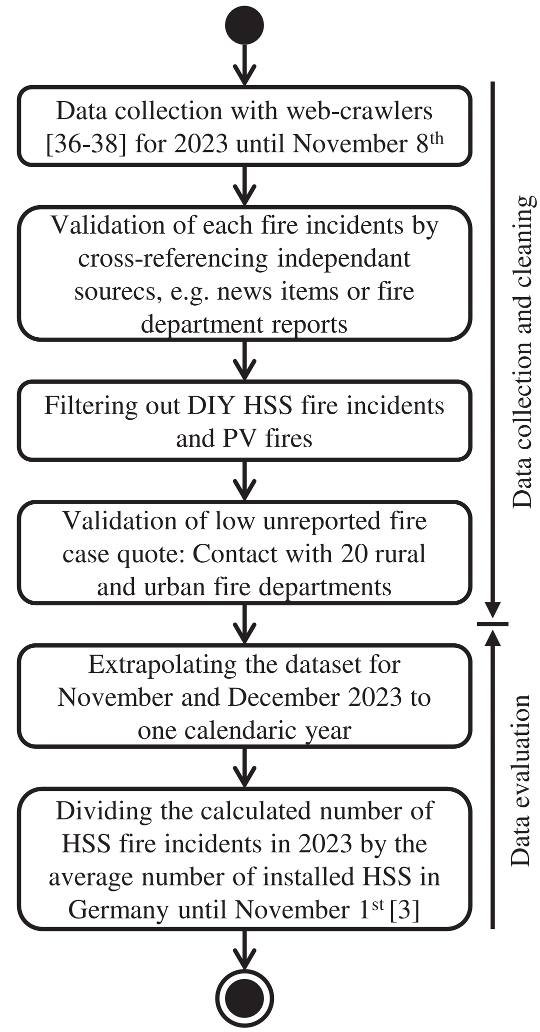

Fig. 1. Flow chart diagram of methodology for HSS fire risk. The data evaluation is described in detail in Section 3.5.

Table 1
Share of residential fires in all fire types in 2020 [20].

Country	Share of residential fires [%]
Belgium	21.5
Bulgaria	10.1
Croatia	8.1
Cyprus	1.0
Czech Republic	19.5
Denmark	27.5
Estonia	14.9
Finland	21.3
France	28.8
Hungary	30.9
Latvia	5.7
Liechtenstein	33.3
Lithuania	18.0
Poland	24.5
Romania	5.3
Slovakia	6.6
Slovenia	29.4
Sweden	27.7
Ukraine	71.4
Average	21.34

$$P\left(fires\_res. \Big/ year\right) = \frac{n_{res.fires.year}}{n_{res.buildings}} \quad (1)$$

This results in a fire probability of **0.28 %** per year for residential buildings in Germany (see Table 2).Statistically, a residential building suffers from a fire every 357 years.

Fig. 2 shows the causes of fires in residential buildings as a percentage [12]. Electricity accounts for the largest share (32 %), followed by human mishandling. As this publication deals with electrical fires, these are discussed below. Most electrical fires are caused by electrical appliances (53 % = $p_{electrical\ devices\ fires,year}$) (Fig. 3). Cooling units, tumble dryers, dishwashers, and washing machines account for the largest share. In the case of electrical installations (26 %), sockets/cables and distribution boards cause the most fires [13]. Due to the predominant contribution of cooling units and tumble dryers to the incidence of electrical fires, an assessment of their respective fire probabilities is conducted herein. The number of fires per electrical appliance category in Germany ($n_{fires,year}$) is determined using the following Formula (2):

$$n_{fires.year} = n_{residential\ fires.year} \cdot p_{electricity\ fires.year} \cdot p_{electrical\ devices\ fires.year} \cdot p_{fires\ in\ each\ device\ categorie.year} \quad (2)$$

For the number of residential fires per year ($n_{residential\ fires,year}$) the value of the residential fires in Germany (average fires in Table 2) is used. The proportion of house fires caused by electricity ($p_{electricity\ fires,year}$) is shown in Fig. 2. $p_{electrical\ devices\ fires,year}$ describes the proportion of electrical fires caused by fires in electrical appliances (53 %). Table 3 shows the proportion ($p_{fires\ in\ each\ device\ category,year}$) of how many fires were triggered per category (cooling unit or tumble dryer).

The number of fires per category (cooling units and tumble dryers) can be found in Table 3.

For determination of fire probabilities on electrical appliance level, the total number of cooling units and tumble dryers in Germany is missing. Therefore, the average number per appliance per household is multiplied by the number of households in Germany. With a number of 40.9 million households, this results in 74.6 million cooling units and 17.67 million tumble dryers [14,15]. Formula (3) is used to calculate the fire probabilities per category of electrical appliances and year.

$$P(fire\ in\ electrical\ device) = \frac{n_{fires.year}}{n_{devices\ in\ category}} \quad (3)$$

This results in a fire probability of 0.0012 % for cooling units and 0.0037 % for tumble dryers per year as described in Table 3.

3.2. Probability of PV fires

The fire incidents assessment presented by Laukamp et al. is considered as the basis for this study [25]. Based on these assessments, 180 fire incidents were triggered by PV systems in Germany between 1995 and 2012. Out of those, 157 incidents were recorded between 2005 and 2012. As illustrated in Fig. 4, a clear correlation between the number of PV fires and the total installed capacity is visible while the ratio of number of fires and capacity stays constant.

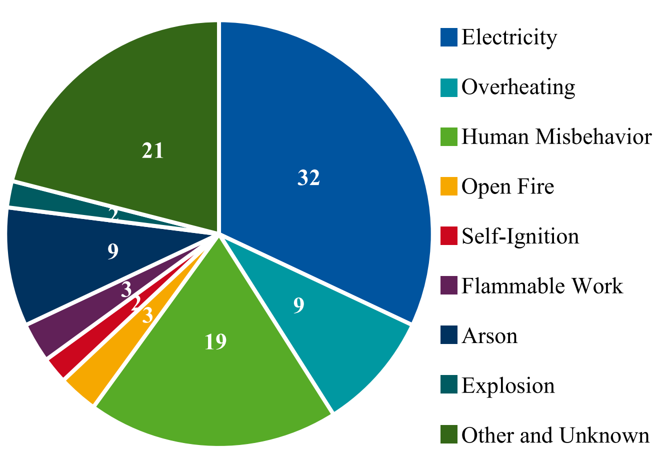

Fig. 2. Fire causes in % from 2002 to 2022 in Germany. (Illustration based on [21].)

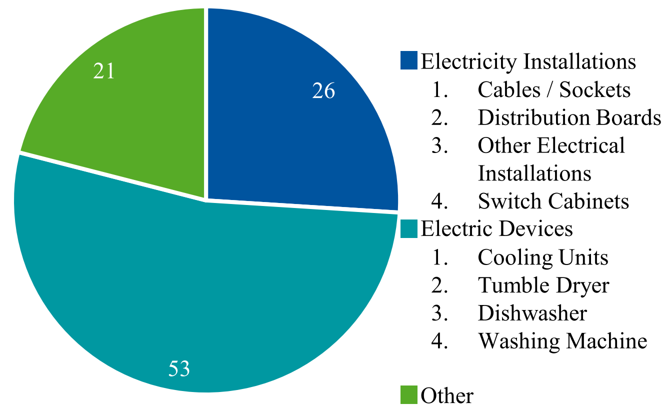

Fig. 3. Electricity fire causes in % from 2002 to 2022 in Germany. (Illustration based on [21].)

Upon calculation of PV triggered fires per MW installed capacity over these 8 years, the value ranges from 0.0005 to 0.0018 fires, as presented in the table below. The weighted average of these eight years is found to be 0.0016 per MW installed capacity per year in Germany (see Table 4).

Looking at the cumulative installed capacity and the number of installations in both private and commercial sectors over the last 10 years, the average size of a PV system in Germany has been around 25 kWp (Appendix 0) [41]. Here the unit kWp (kilowatt peak) refers to the maximum power output of a photovoltaic system under standard test conditions and is commonly used to indicate the capacity of PV system installations. Assuming a linear relationship between PV system size and fire risk, the previously calculated annual fire risk per MW can be used for an average-sized PV system in Germany as follows:

$$= \frac{25\ kWp}{1\ MWp} \times 0.0016 = 0.00004 = \mathbf{0.004}\%$$

Given the primary focus of this study on German households, it becomes important to calculate the fire risk of PV systems installed for single and multifamily residences as well. Typically, these installations range from 2 kWp to 30 kWp in capacity [42]. According to Figgener et al., based on the number of systems within this capacity range, the

Table 2
Fire probability for general house fires per year [%].

	NRW	Germany
Residential buildings	3,950,000 [38]	19,500,000 [39]
Fires procedure 1	12,291 [19]	59,956
Fires procedure 2		49,082
Average fires		54,519
Fire probability per year [%]		**0.28**

Table 3
Fire probability in electrical devices.

	Cooling units	Tumble dryer
Share of device in electrical device fire cause [%] ($p\_{fires\ in\ each\ device\ category,year}$)	10	7
Fires in devices ($n_{fires,year}$)	925 [22]	648 [22]
Share of the device in the household	1.82 [23]	0.432 [23]
Devices in Germany ($n_{decvices\ in\ category}$)	74,600,000 [23,24]	17,670,000 [23,24]
Fire probability per year [%]	**0.0012**	**0.0037**

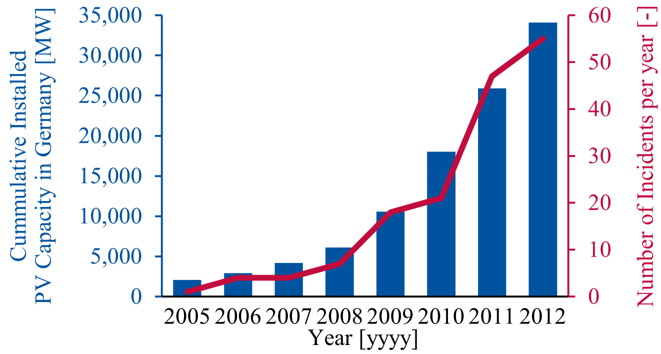

Fig. 4. Increasing number of PV-triggered fires with increasing installed capacity in Germany.
(Illustration based on [25,40].)

average size in 2022 is determined to be 9 kWp [43]. Therefore, assuming the same linear relationship between PV system size and fire risk, the fire risk for a German household with an average-sized PV system can be calculated as follows:

$$= \frac{9\ kWp}{1\ MWp} \times 0.0016 = 0.0000144 = \mathbf{0.0014}\%$$

Based on a fault tree analysis of the fire incidents in Germany, Mohd et al. present the contribution of different components as shown in Fig. 5 [26]. The PV module, inverter and connectors triggered around 75 % of the analyzed fire incidents of PV systems. Literature suggests, that arcing, overheating, physical damage, manufacturing defects, and installation errors are the primary causes of fires in PV modules and inverters [44]. In the case of connectors, manufacturing and installation errors are the primary cause of fires. In addition, as the connectors are prone to physical damage through weathering effects and animal bites, they can be a source of arcing [26,44].

Table 4
Probability of PV-triggered fires per MW installed capacity per year in Germany. Own calculations based on [25,40].

Year	Number of Fire incidents [25]	Cumulative Yearly installed Capacity [MW] [40]	PV triggered fires per MW	Weighted Average [PV-triggered fires/ MW/year]
2005	1	2,056	0.0005	0.0016
2006	4	2,899	0.0014	
2007	4	4,170	0.0010	
2008	7	6,120	0.0011	
2009	18	10,566	0.0017	
2010	21	18,006	0.0012	
2011	47	25,916	0.0018	
2012	55	34,077	0.0016	

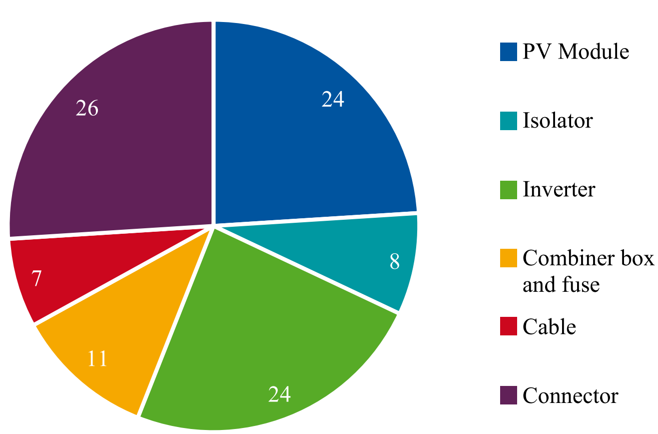

Fig. 5. Contribution of different components in PV system-triggered fires in Germany.
(Illustration based on [26].)

3.3. *Probability of vehicle fires*

In this section, the initial fire risk of an electric vehicle (battery electric vehicle (BEV) and plug-in-hybrid) is discussed, and subsequently, it is compared with that of an ICE vehicle.

Due to the lack of credible studies on fires in Germany, a comprehensive study presented by Mohd and Martín-Gómez is used here for further comparative analysis [27]. In the mentioned study, EV fire incidents from different countries are analyzed between 2015 and 2022, based on the publicly available study and reports. Fire incidents from South Korea are also considered along with a few European countries, namely, Denmark, The Netherlands, Norway, Sweden and Finland. However, as vehicle regulations, standards, weather conditions, and driving behavior in South Korea are different than that of Germany, a revised calculation has been performed, excluding South Korea, as delineated in Appendix G. Considering the weighted average of fire risk in investigated European countries, it is concluded, that the annual fire risk of EVs in Germany is **0.021 %** per registered EV. Considering the stock of 2.2 million EVs in Germany in October 2023, this fire risk projects to around 465 EV fires in Germany in the year 2023 until October [1].

Further Mohd et al. present a fault tree analysis of the fire incidents in Denmark, Netherlands, and Sweden, as the cause of fires are also reported in the publicly available reports of these countries (Fig. 6) [27]. According to this analysis, after 'Unknown unreported factors', 'Vehicle factors' and 'External factors' are the major factors stemming 42 % of the EV-triggered fires. 'Vehicle factors' encompass the factors relating to inherent characteristics, conditions, or faults within the battery or other vehicle components. On the other hand, 'External factors' represent elements typically beyond the control of vehicle manufacturers, owners, or operators, such as animal interference, natural phenomena, and external building fires.

When it comes to ICE vehicles, according to statistics from the German Insurance Association (GDV), around 40,000 fires are caused by ICE vehicles in Germany every year [30]. The KBA publishes that there are around 45 million ICE vehicles in 2023 [45]. Using these two numbers, the probability of ICE vehicle fires can be determined as follows:

$$= \frac{40,000\ fires}{45\ million\ vehicles} = 0.00089 = \mathbf{0.089}\%$$

To compare the fire risk between electric vehicles with Plug-in-Hybrids and vehicles with combustion engines, the fire probabilities

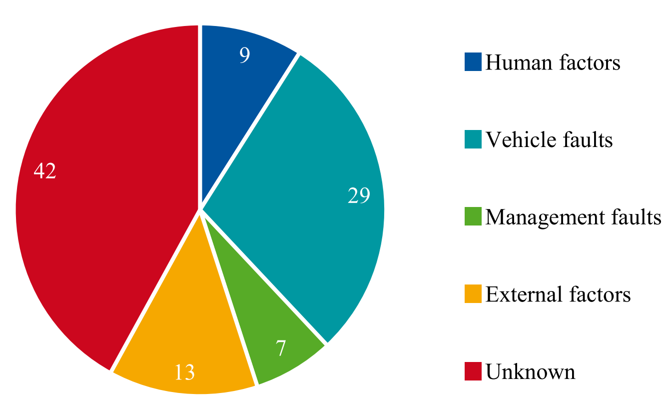

Fig. 6. Contribution of different components in EV-triggered fires in Germany.
(Illustration based on [27].)

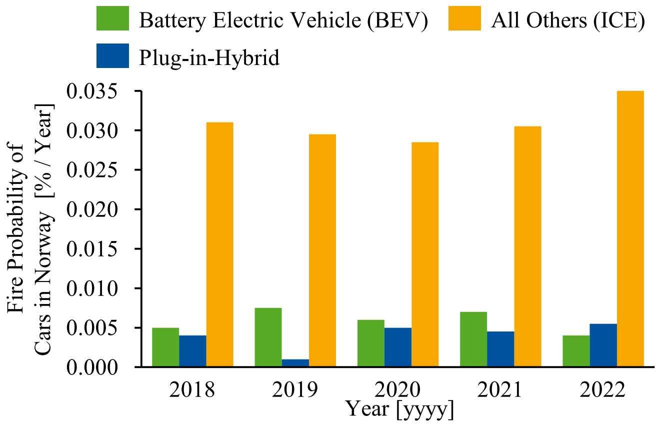

Fig. 7. Fire probability of vehicle categories per year in Norway. (Illustration based on [31].)

per year for these vehicle variants for Norway are shown in Fig. 7 [31]. As of October 2023, there are a total of 600,000 battery electric and plug-in-hybrid vehicles in Norway [27].

The probability of fires in EVs (both BEVs and Plug-in-Hybrids) in Norway is on average around five times lower than that of a fire in the combustion variant. ICE vehicles are on average significantly older than electric vehicles and therefore problems and faults appear more frequently in these older cars. In addition, faults and problems occur more frequently than average in first-generation vehicles [31].

3.4. Probability of large-scale storage fires

In the assessment of large-scale storage systems, the BESS Failure Event Database serves as the main data source, spanning from 2015 to 2023 and documenting a total of 67 recorded cases [32]. The distribution of incidents across these years is generally uniform, except for an anomaly in 2018, where all 16 incidents (24 %) were specifically reported in Korea.

BloombergNEF reports 56 GWh of installed energy in 2021 as well as installed power excluding pump-hydro storage from 2015 to 2023 for large-scale energy storage systems [33]. It is presumed that these figures are representative of the broader landscape of large-scale battery storage systems, given the predominant role of batteries within the overall energy storage systems [46,47]. Additionally, Murray [34] contributes data on newly installed energy from 2020 to 2023. Leveraging this information and the installed capacity of 56 GWh in 2021, cumulative capacities for the years 2019 to 2023 are derived, resulting in average C-rates from 0.42 in 2023 to 0.67 in 2019 (see Table 5). The C-rate (charge/discharge rate) indicates how quickly a battery can be charged or discharged relative to its total capacity. For example, a C-rate of 1.0 means the battery can be fully charged or discharged in 1 h, while a C-rate of 0.5 means this process takes 2 h. Adopting a conservative approach for fire risk evaluation per capacity, the highest C-rate of 0.67

Table 5
Installed global power and energy for battery storage systems [33,34]. (*) marks estimated values.

Year	Power [GW]	Energy [GWh]	C-Rate [1/h]
2015	4 [33]	6*	0.67*
2016	5 [33]	7.5*	0.67*
2017	7 [33]	10.5*	0.67*
2018	10 [33]	15*	0.67*
2019	14 [33]	21 [33,34]	0.67
2020	18 [33]	29 [33,34]	0.62
2021	27 [33]	56 [33]	0.48
2022	44 [33]	99 [33,34]	0.44
2023	72 [33]	173 [33,34]	0.42

is utilized to estimate energy capacities for 2015 to 2018.

These derived capacities contribute to the calculation of yearly fire probabilities, which range from 0 % per MWh in 2015, where no incidents were reported, to 0.11 % per MWh in 2018, marked by 16 recorded incidents. The specific numerical breakdown per year is visually presented in Fig. 8. The average fire risk, therefore, amounts to **0.015 %** fire incidents per registered MWh per year.

3.5. Probability of home storage system fires

We define the probability of a fire incident as the number of incidents for a specific year $n_{incidents,year}$ divided by the total number of installed HSS n_{HSS} for this year (see Formula 4). Our investigation reveals a total of 6 incidents in the year 2022 and 32 incidents in 2023 up until November 8th. Out of all the incidents found in Germany in the year 2023, 17 incidents took place in the states NRW and Bavaria, which also account for 41 % of the national cumulative installed HSS capacity as of November 1st, 2023. Presentation of such correlation between the state-wise number of fire incidents and the cumulative installed HSS capacities through Fig. 9 serves as a validation for the identified cases up to a certain extent.

Extrapolating this data (Formula 5) from 2023 for the entire year of 2023 yields a theoretical estimate of 37.5 incidents. As many HSS have been installed in 2023 in Germany, we chose the average number of installed HSS for 2023 as n_{HSS} for a fair comparison (Formula 6). This amounts to 820,919 installed HSS. Applying Formula 4 to these numbers, we compute a fire probability of 0.0046 % per HSS for 2023. Despite having validated the data (see methodology), we reduce the reported accuracy to one significant digit (0.005 %) to account for data extrapolation for November and December 2023, as well as potentially unreported fire incidents. This leads to a 20 % margin of error, as even with 45 potentially reported fire incidents, the value would remain at 0.005 %.

Furthermore, climate conditions in November and December do not suggest a higher fire incident rate than for the rest of the year. Therefore, we consider 0.005 % a reliable upper bound for HSS fire probability given current technology and climate conditions in Germany.

Considering the total number of HSS installations, the 6 incidents for 2022 might be underreported. Due to the higher media awareness, we concentrate on the incidents that could be found for 2023.

$$P\left(HSSfire \middle/ year\right) = \frac{n_{incidents,year}}{n_{HSS}}. \tag{4}$$

$$n_{incidents,year} = \frac{n_{incident,data}}{n_{HSS}} \times \frac{12\ months}{month_{study}} \tag{5}$$

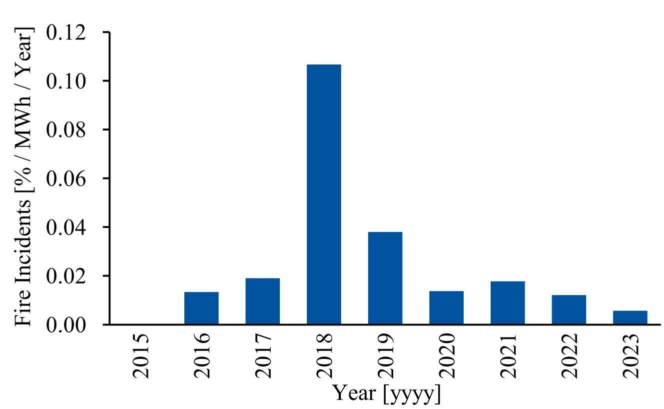

Fig. 8. Fire risk of large-scale BESS. (Illustration based on [32–34].)

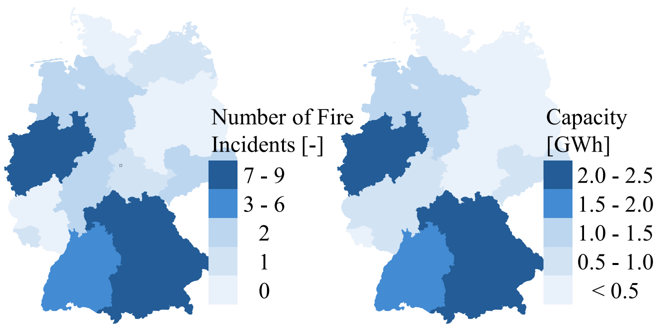

Fig. 9. State-wise number of HSS fire incidents in 2023 (Left) & state-wise installed home storage capacity in GWh on 01.11.2023 (Right). (Illustration based on [2].)

$$n_{HSS} = \frac{\sum_{i=0}^{n_{months}} n_{HSS,i}}{n_{months}} \tag{6}$$

Figs. 10 and 11 show a visual representation of the 38 fire incidents that occurred in 2022 and 2023. The distribution of HSS fire incidents appears uniform throughout the year, with a subtle suggestion of lower fire risk during June/July and November/December and January. However, given the limited sample size, this observed pattern may potentially be an outlier. Notably, as of the study's conduct in November 2023, only one incident from December 2022 is included.

For the fire incident distribution for the time of day, Fig. 11 shows a consistent rise in the number of incidents from the morning to afternoon (2 pm to 4 pm). This observation shows a strong correlation with the time period we expect an HSS to reach the state of full charge.

If we compare the fire probabilities of HSS with EV and large battery storage systems per energy (see Fig. 12), it is noticeable that the fire probability per MWh of a large battery storage system is significantly lower (**0.015 %**, see Appendix D). This is because a large battery storage system has a significantly higher energy capacity than an HSS or an EV. Larger battery storage systems tend to have larger power electronic devices attached. However, there are no clear indications that larger power electronic devices have a higher fire probability. Therefore, the probability of a fire caused e.g. by the power electronics is distributed on a higher total capacity. The fire probabilities per energy capacity for HSS and EV are calculated as in Formula (7). Results can be seen in Table 6.

$$P\left(fire \middle/ MWh\right) = \frac{P(x/year)}{\text{average storage capacitiy}}, x \in \left\{HSSfire, EVfire\right\} \tag{7}$$

To calculate the average size of an HSS/EV battery, the total energy capacity is divided by the number of systems. The fire probability per MWh of a home storage system (**0.56 %**) is slightly lower than that of an electric vehicle **(0.59 %)**.

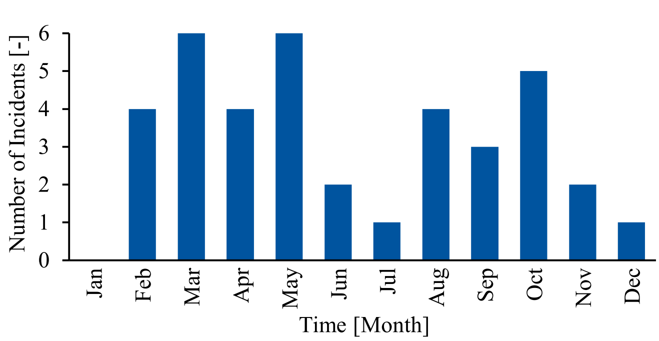

Fig. 10. Distribution of the fire incidents analyzed in 2022 and 2023 over the months.

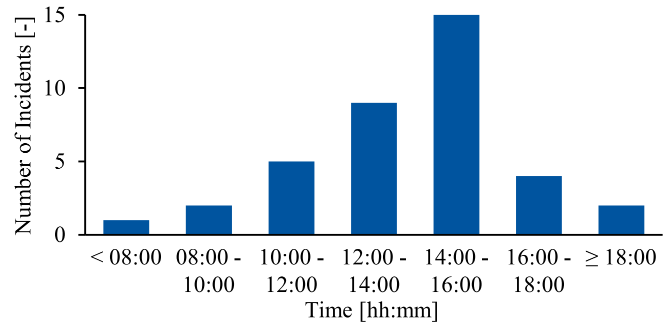

Fig. 11. Distribution of the fire incidents analyzed in 2022 and 2023 over the time of day.

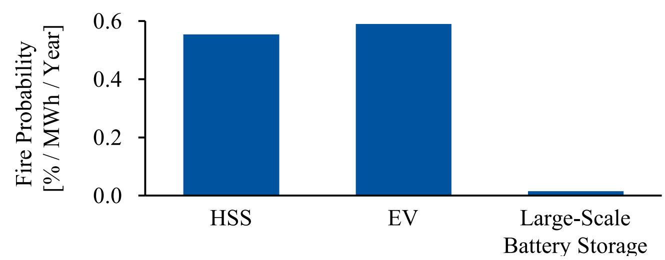

Fig. 12. Comparison of fire probabilities per MWh.

Table 6
Fire probabilities for HSS and EV fire in %.

	HSS	EV
Entire energy capacity [GWh]	9.2 [2]	90.82 [1]
Number of systems	1,044,110 [2]	2,210,505 [1]
Average storage capacity [kWh]	8.81	41.08 kWh
P(fire per system per year) [%]	0.005	0.024
P(fire per MWh per year) [%]	**0.56**	**0.59**

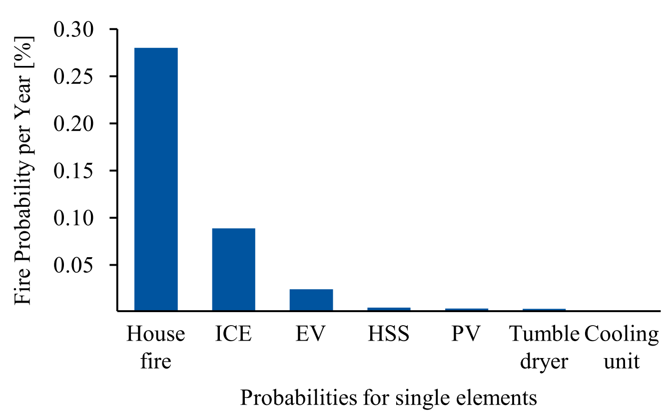

Fig. 13. Comparison of the fire probabilities of all described elements.

Comparing the fire probabilities per system (number) and year (Fig. 13), it is visible that the probability of a general house fire (not related to PV or HSS) is significantly higher than that of the other categories (**0.28 %** per year). The probability of a HSS fire per year is approximately 50 times lower (**0.005 %**). With an EV fire probability of **0.021 %** per year, an HSS fire is five times less likely than an EV fire. Furthermore, the probability of an ICE fire (**0.089 %**) is approximately four times higher than that of an EV fire. Comparison of the fire probabilities of all described elements.

The probability of an HSS fire per year (**0.005 %**) is approximately at the same level as that of fires in tumble dryers (**0.0037 %**). In addition, the probability of PV fires (**0.0014 %**) is also in this dimension. Only the probability of fires in cooling units (**0.0012 %**) per year is four times lower than that of a HSS fire. A comparison of the stationary systems only can be found in Appendix E.

4. Case study

After outlining the fire risk posed by individual systems, it is essential to aggregate these findings within the context of a typical German household, which serves as the central focus of this study. For this purpose, we assume a representative middle to high-income German household that is eager to contribute to the energy transition. Recognizing the pivotal roles played by PV systems, HSS, and EVs in the energy transition, such a household may possess one or a combination of these technologies.

Primarily, each household faces an annual constant fire risk of 0.28 % as elaborated in Section 3.1. Moreover, if the house is equipped with an average-sized PV system of 9 kWp, it is exposed to an additional fire probability of 0.0014 %. As explained in Section 3.2, here fire risk for an average-sized 'residential PV system' is considered. Generally, PV systems are more profitable when used in combination with HSS [48,49]. Therefore, if the household is also equipped with one HSS, it is subjected to an additional fire probability of 0.005 % (refer to Section 3.5). Finally, ownership of one EV or one ICE vehicle by the household further raises the fire risk by 0.0021 % and 0.089 %, respectively, as explained in Section 3.3. For a better overview, all the fire probabilities are summarized in Table 7 below.

Now by considering these fires as entirely independent events, where each probability signifies the fire risk associated solely with that specific system, we can calculate the overall fire risk posed by a combination of systems using the theorem of 'multi-event additional probability for independent events'. According to the theorem, the probability of independent events A or B occurring is calculated using Formular (8).

$$P(A\ or\ B) = P(A) + P(B) – P(A\ and\ B) \tag{8}$$

Here, the last term 'P(A and B)' is the probability of events A and B occurring at the same time, and therefore it is subtracted from the addition to avoid double counting. By applying the same approach to the considered German household equipped with only a PV system, the annual fire risk faced by the household can be calculated using Formula (9).

$$P(House\ or\ PV) = P(House) + P(PV) - P(House\ and\ PV) \tag{9}$$

The last term 'P(House and PV)' denotes the probability of 'General house fire' and 'PV-triggered fire' occurring independently and in the same year. As this term is very small (3.9×10^{-4} %), it can be neglected in the calculation.

Similarly, for 3 events - 'A', 'B', and 'C', the additional probability is calculated using Formula (10).

$$\begin{aligned} \mathrm{P(A\ or\ B\ or\ C)} = \mathrm{P(A)} + \mathrm{P(B)} + \mathrm{P(C)} - P(A\ and\ B) - P(A\ and\ C) \\ - P(B\ and\ C) + P(A\ and\ B\ and\ C) \end{aligned} \tag{10}$$

By applying this methodology and ignoring negligible terms, fire risk is calculated for the considered German household possessing the combination of different systems. Fig. 14 shows these results firstly as they are on the left-hand side and secondly enlarged with a cross-sectional axis on the right-hand side. As it can be seen in the enlarged view on the right side, primarily, each household faces an annual constant fire risk of 0.28 %. The reference case of owning a house and an ICE has a fire probability of 0.37 %. In contrast, if the household decides to own an EV instead, a PV system and an HSS the total annual fire risk would decrease by 16 % to 0.31 %.

The subtraction of any electrical household appliances decreases the theoretical risk of a house fire, however on very low margins. For instance, omitting an EV would reduce the fire probability to 0.29 %. Additionally, omitting an HSS would lower the probability to 0.28 %. Finally, omitting a PV system would reduce the fire probability by 0.5 %. This corresponds to a relatively low decrease in the annual fire probability.

Table 7
Annual fire risk faced by a representative German household possessing different systems.

	Residential building	PV System	Home Storage System	Electric Vehicle	ICE Vehicle
Annual fire probability [%]	**0.28**	**0.0014**	**0.005**	**0.021**	**0.089**

5. Discussion and limitations

This study encountered several challenges attributed to the absence of a standardized fire incident reporting system in Germany, particularly where most states employ broad categorizations for such incidents. To overcome this information gap, web crawlers were utilized. However, it is essential to acknowledge the inherent limitation of this approach, as unreported cases, albeit likely minimal, are anticipated.

A notable constraint in this media-centric research is the growing polarization of reported HSS fires. This phenomenon has resulted in a higher incidence of reported cases relative to the number of installed HSS units in 2023 compared to 2022. As a result of this skew, only the fire probability for 2023 could be computed, and a direct comparison or average with the preceding year is unattainable. Additionally, it is important to recognize the inherent biases and potential inaccuracies in media information. As each incident has been thoroughly investigated and filtered as described, the calculated fire probability of HSS in this study should be seen as the minimum probability.

Moreover, we encountered two additional challenges during the research process: Firstly, the distribution of responsibilities for processing each fire incident between local fire and police departments contributes to non-uniform data collection practices at the governmental level. This lack of consistency complicates efforts to draw comprehensive conclusions from available data. Secondly, during our data collection and validation, we were faced with obstacles due to Germany's stringent privacy standards, posing a hindrance to obtaining a complete and accurate dataset.

Similar to HSS fires, we observed the absence of a standardized fire incident reporting system for PV-, EV-, and ICE-related fires in Germany. As a result, the calculation of fire probabilities for these components relies on foundational studies referenced in the Methodology and Results sections. The accuracy of our findings is therefore inherently dependent on the reliability and limitations of these foundational studies.

Another important limitation of this study is that it focuses solely on the probability of HSS fires occurring and does not analyze the severity or potential damage caused by these fires. We acknowledge that the fire effects of different energy storage and fuel systems—such as burning oil tanks, gas tanks, or HSS—are not directly comparable. The same applies to vehicles with different drive types. While we reference comparisons to other fire incidents, such as house fires or burning appliances like clothes dryers, we recognize that these comparisons may not fully capture the differences in fire dynamics, energy content, and possible consequences.

In particular, we are aware that the severity of an HSS fire is likely to be significantly higher than that of a burning tumble dryer. Unlike household appliances, HSS contain stored electrical energy, which can lead to thermal runaway events, high-temperature fires, and potentially hazardous gas emissions. This fundamental difference means that even if the probability of an HSS fire is lower than that of a general house fire,

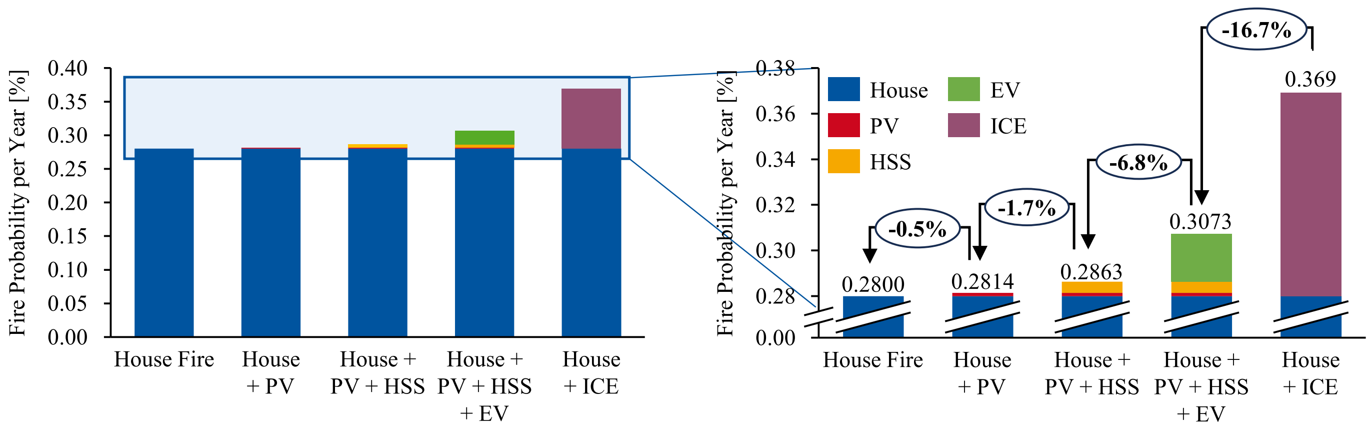

Fig. 14. Posed annual fire risk for the considered case study possessing the combination of different systems.

the possible consequences may be more severe.

However, our primary objective is to provide a statistical analysis of fire probabilities rather than an in-depth examination of fire severity. These aspects warrant further investigation but are beyond the scope of this study. In addition, evaluation of the incident reports suggests correlations between the location of the HSS and the damage caused by an HSS fire as a fire in a lower value compartment of the property seems to cause lower overall financial losses. Furthermore, feedback from fire departments suggest that an easily accessible location might be advantageous in case of an HSS fire.

6. Summary and outlook

6.1. Summary

This scientific paper presents a comprehensive quantitative analysis of fires in HSS in Germany in the context of the increasing importance of battery storage in the energy industry. The results show a significantly lower probability of an HSS fire compared to a general house fire. Studies suggest that vehicles with ICE are more likely to be affected by fires than electric vehicles. The analysis presented in this paper shows that the probability of an HSS fire lies even below the EV fire probability. Moreover, the probability of an HSS fire in 2023 is roughly at a comparable level to the probability of a tumble dryer fire. In contrast, the probability of a fire in a PV system or a refrigerator is lower than that of an HSS fire. Depending on the initial site of the installation of the HSS, a potential fire can cause damage higher than of fires caused by cooling units or tumble dryers. During the last years, there were further improvements within the safety aspects of HSS. This might affect future fire probabilities to further decrease. These findings contribute to a deeper understanding of the risks of battery storage systems in the domestic environment and enable a well-founded consideration in the context of the integration of renewable energy systems.

6.2. Outlook

To address the presented challenges and enhance the reliability of future research, efforts should be directed towards establishing a more standardized reporting framework, fostering collaboration between relevant authorities. As long as there is no data collection standard developed by the authorities, the media research, as presented in this study, should be continued, to monitor the fire probabilities in the coming years. Thereby, due to the longer observation period, more reliable data could be sourced. Future research should complement our findings by assessing fire impact severity and potential consequences in more detail.

CRediT authorship contribution statement

Florian Hölting: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aniket Kapse:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Fabian Breer:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jan Figgener:** Writing – review & editing, Supervision, Resources, Methodology, Data curation, Conceptualization. **Mark Junker:** Writing – review & editing, Supervision, Resources, Methodology, Data curation, Conceptualization. **Dirk Uwe Sauer:** Writing – review & editing, Resources, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Florian Hoelting reports financial support was provided by Bundesverband Energiespeicher Systeme e.V. If there are other authors, they 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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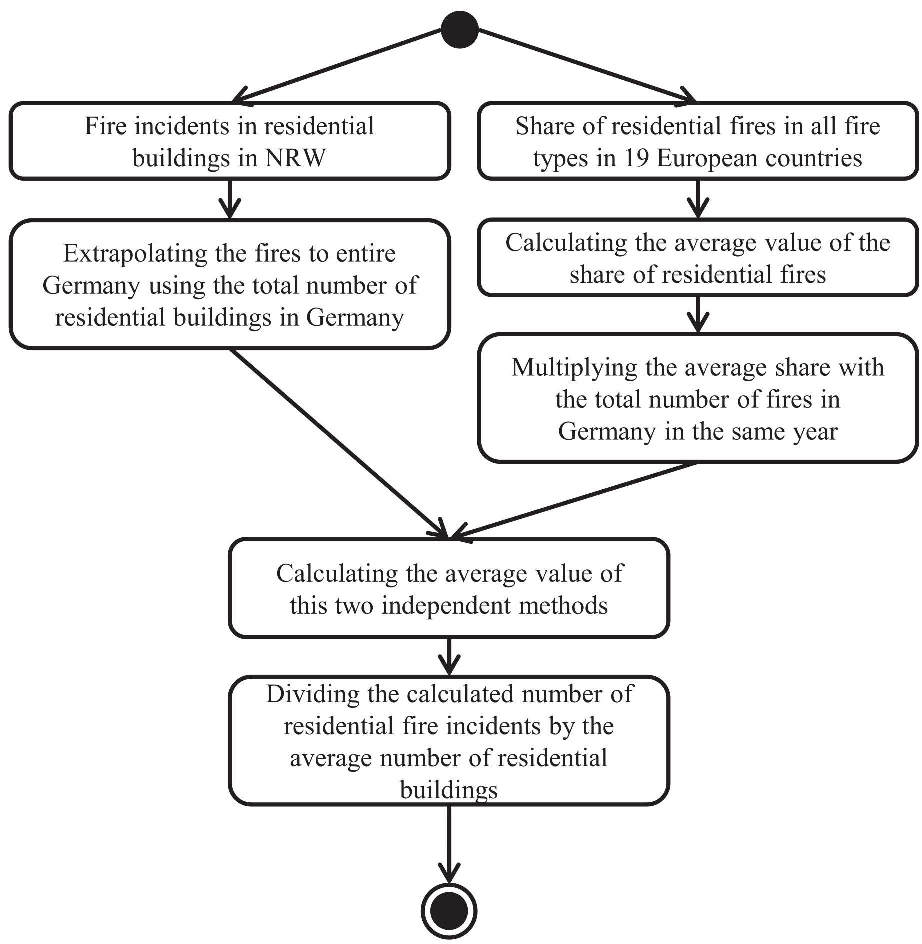
Appendix A. Abbreviations and nomenclature

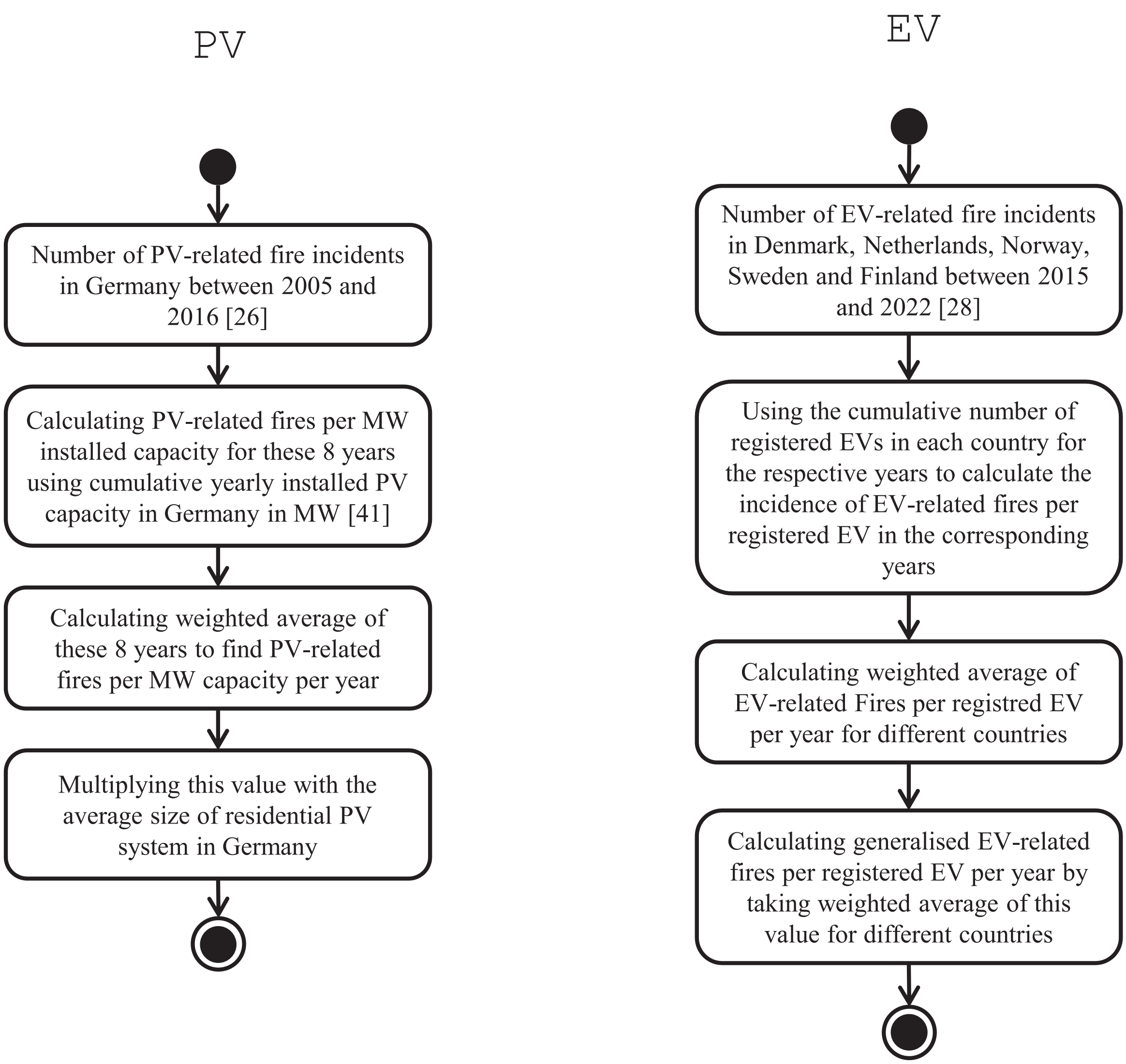
Table 8
Abbreviations are sorted alphabetically.

BEV	Battery electric vehicle
EV	Electric vehicle
HSS	Home storage system
ICE	Internal Combustion Engine
NRW	North Rhine-Westphalia
PV	Photovoltaic

Appendix B. Flow chart diagram for calculating the house fire probability



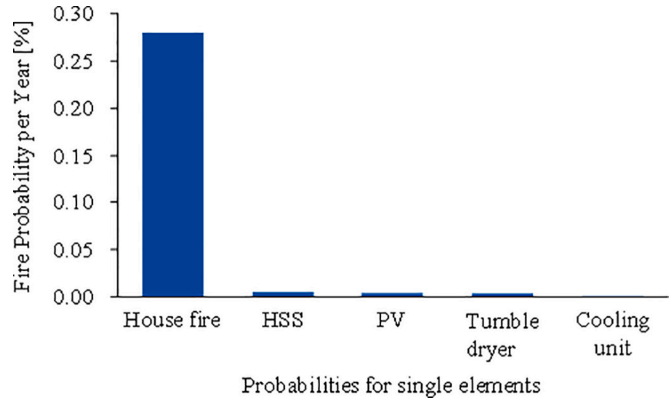
Appendix C. Flow chart diagram for calculating the probability of PV and EV fires



Appendix D. Search strings

[Energie, Strom, PV, Solar, Photovoltaik, Fotovoltaik, Sonnen]
[Speicher, Batterie, Akku, Zelle, Modul, Wechselrichter, Inverter, Anlage, System, Keller, Garage, Schuppen, Haus]
[Verpuffung, Explosion, Feuer, Brand, Rauch, Schmor, Flamm, Einsatz, Feuerwehr, Feuerlöscher, Verletzt, Schaden, Überhitzung, Kurzschluss, Defekt]

Appendix E. Comparison of the fire probabilities of all stationay elements



Appendix F. Cumulative installed PV capacity and number of PV systems in Germany [41]

Year	Installed capacity in MW	Number of installed systems	Average capacity per system in kWp
2013	36,710	1,449,413	25.33
2014	37,900	1,521,365	24.91
2015	39,224	1,572,922	24.93
2016	40,679	1,622,405	25.07
2017	42,293	1,686,993	25.07
2018	45,207	1,760,396	25.68
2019	48,864	1,863,679	26.22
2020	54,309	2,041,010	26.61
2021	60,027	2,275,897	26.37
2022	67,499	2,665,673	25.32

Appendix G. Number of EV fires per registered EV per year in different countries [27]

Country	Year	Number of Fires	Cumulative number of registered EV	EV Fires/Registered EV	Weighted Average EV Fires/Reg EV/year	Weighted Average of EV-related Fires/Reg EV/year
Denmark	2018	3	10,541	2.85E-04	6.52E-04	2.11E-04
	2019	10	15,205	6.58E-04		
	2020	18	25,345	7.10E-04		
Netherlands	2020	71	270,303	2.63E-04	2.92E-04	
	2021	118	381,335	3.09E-04		
Norway	2016	17	97,532	1.74E-04	9.97E-05	
	2017	28	138,983	2.01E-04		
	2018	8	195,351	4.10E-05		
	2019	18	260,692	6.90E-05		
	2020	24	340,002	7.06E-05		
	2021	32	460,734	6.95E-05		
	2022	24	599,169	4.01E-05		
Sweden	2018	8	156,331	5.12E-05	4.96E-05	
	2019	6	207,904	2.89E-05		
	2020	20	308,485	6.48E-05		
	2021	24	452,413	5.30E-05		
	2022	23	610,716	3.77E-05		
Finland	2015	1	1587	6.30E-04	3.04E-04	
	2016	2	3285	6.09E-04		
	2017	0	7168	0.00E+00		
	2018	3	15,499	1.94E-04		
	2019	3	29,364	1.02E-04		

Data availability

Data will be made available on request.

References

[1] Mobility Charts, Mobility Charts. https://mobility-charts.rwth-aachen.de/, 2023. (Accessed 5 December 2023).
[2] Battery Charts, Battery Charts. https://battery-charts.rwth-aachen.de/, 2023. (Accessed 5 December 2023).
[3] J. Figgener, C. Hecht, D. Haberschusz, J. Bors, K.G. Spreuer, K.-P. Kairies, P. Stenzel, D.U. Sauer, The Development of Battery Storage Systems in Germany: A Market Review (Status 2023), 2022.
[4] G. Angenendt, S. Zurmühlen, H. Axelsen, D.U. Sauer, Comparison of different operation strategies for PV battery home storage systems including forecast-based operation strategies, Appl. Energy 229 (2018) 884–899, https://doi.org/10.1016/j.apenergy.2018.08.058.
[5] DEVK, DEVK-Umfrage: Brennen E-Autos häufiger als Diesel oder Benziner?, DEVK Versicherungen, 24 November, 2021.
[6] D. Baur, P. Emmerich, M.J. Baumann, M. Weil, Assessing the social acceptance of key technologies for the German energy transition, Energy Sustain. Soc. 12 (2022) 1–16, https://doi.org/10.1186/s13705-021-00329-x.
[7] S. Enkhardt, Explosion eines 30-Kilowattstunden-Batteriespeichers zerstört Wohnhaus, PV Magazine, 2023, 13 October, https://www.pv-magazine.de/2023/10/13/explosion-eines-30-kilowattstunden-batteriespeichers-zerstoert-wohnhaus/. (Accessed 5 December 2023).
[8] S. Enkhardt, Weitere Brände von Photovoltaik-Batteriespeichern im September, PV Magazine, 2023, 9 October, https://www.pv-magazine.de/2023/10/09/weitere-braende-von-photovoltaik-batteriespeichern-im-september/. (Accessed 5 December 2023).
[9] Sandra Enkhardt, Senec-Kunden mit V3- und V2.1-Systemen sollen kostenlos neue LFP-Speicher erhalten. https://www.pv-magazine.de/2023/11/24/senec-kunden-mit-v3-und-v2-1-systemen-sollen-kostenlos-neue-lfp-speicher-erhalten/, 2023. (Accessed 5 December 2023).
[10] LG ESS Battery, Freiwillige Korrekturmaßnahme. https://www.lgessbattery.com/de/home-battery/news-view.lg?blcSn=1417, 2022. (Accessed 9 February 2024).
[11] Q. Wang, B. Mao, S.I. Stoliarov, J. Sun, A review of lithium ion battery failure mechanisms and fire prevention strategies, Prog. Energy Combust. Sci. 73 (2019) 95–131, https://doi.org/10.1016/j.pecs.2019.03.002.
[12] Q. Wang, P. Ping, X. Zhao, G. Chu, J. Sun, C. Chen, Thermal runaway caused fire and explosion of lithium ion battery, J. Power Sources 208 (2012) 210–224, https://doi.org/10.1016/j.jpowsour.2012.02.038.
[13] C. Hendricks, N. Williard, S. Mathew, M. Pecht, A failure modes, mechanisms, and effects analysis (FMMEA) of lithium-ion batteries, J. Power Sources 297 (2015) 113–120, https://doi.org/10.1016/j.jpowsour.2015.07.100.
[14] E.J. Archibald, Fire & Explosion Hazards Due to Thermal Runaway Propagation in Lithium-Ion Battery Systems, PhD Dissertation,, Austin, 2021.
[15] A.R. Baird, E.J. Archibald, K.C. Marr, O.A. Ezekoye, Explosion hazards from lithium-ion battery vent gas, J. Power Sources 446 (2020) 227257, https://doi.org/10.1016/j.jpowsour.2019.227257.
[16] A.F. Blum, R.T. Long, Fire Hazard Assessment of Lithium Ion Battery Energy Storage Systems, Springer, New York, New York, NY, 2016.
[17] C.S. Meliá, R. Stølen, B.G. Olsø, Fire safety challenges with photovoltaics and Li-ion battery system installations in buildings, J. Phys. Conf. Ser. 2885 (2024) 12110, https://doi.org/10.1088/1742-6596/2885/1/012110.
[18] F. Eger, H. Laukamp, Brandrisiken und Schadensfälle bei PV-Heimspeichern: Ergebnisse im Rahmen des Projekts SPEISI, Berlin, 2019.
[19] Ministerium des Inneren des Landes Nordrhein-Westfalen, Gefahrenabwehr: Die Jahresstatistik. https://www.im.nrw/system/files/media/document/file/jahresstatistik-gefahrenabwehr-2022_0.pdf, 2022. (Accessed 8 December 2023).
[20] Center for Fire Statistics, World Fire Statistics 2022, 2022. https://www.ctif.org/sites/default/files/2022-08/CTIF_Report27_ESG_0.pdf (accessed 7 December 2023).
[21] Institut für Schadenverhütung und Schadenforschung der öffentlichen Versicherer e.V., Ursachenstatistik: Brandschäden 2022, 2022.
[22] schadenprisma, Elektrische Brandursachen im Wandel der Zeit. https://www.schadenprisma.de/archiv/artikel/elektrische-brandursachen-im-wandel-der-zeit/, 2023. (Accessed 7 December 2023).
[23] Statistisches Bundesamt, Ausstattung privater Haushalte mit elektrischen Haushalts- und sonstigen Geräten - Deutschland. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Ausstattung-Gebrauchsgueter/Tabellen/liste-haushaltsgeraete-d.html#115474, 2020 (accessed 7 December 2023).
[24] Umweltbundesamt, Bevölkerungsentwicklung und Struktur privater Haushalte. https://www.umweltbundesamt.de/daten/private-haushalte-konsum/strukturdaten-privater-haushalte/bevoelkerungsentwicklung-struktur-privater#843-millionen-menschen, 2023. (Accessed 7 December 2023).
[25] H. Laukamp, G. Bopp, R. Grab, C. Wittwer, H. Häberlin, B. van Heeckeren, S. Phillip, F. Reil, H. Schmidt, A. Sepanski, H. Thiem, in: W. Vaassen (Ed.), PV Fire Hazard - Analysis and Assessment of Fire Incidents, 2013.
[26] N.A.F. Mohd Nizam Ong, M.A. Sadiq, M.S. Md Said, G. Jomaas, M.Z. Mohd Tohir, J.S. Kristensen, Fault tree analysis of fires on rooftops with photovoltaic systems, Journal of Building Engineering 46 (2022) 103752, https://doi.org/10.1016/j.jobe.2021.103752.
[27] M.Z. Mohd Tohir, C. Martín-Gómez, Electric vehicle fire risk assessment framework using fault tree analysis, Open Res Europe 3 (2023) 178, https://doi.org/10.12688/openreseurope.16538.1.
[28] evfiresafe.com, Passenger EV LIB Fire Incidents: Global, as of 30th June 2023, 2023.
[29] M.K. Hassan, N. Hameed, M.D. Hossain, M.R. Hasnat, G. Douglas, S. Pathirana, P. Rahnamayiezekavat, S. Saha, Fire incidents, trends, and risk mitigation framework of electrical vehicle cars in Australia, Fire 6 (2023) 325, https://doi.org/10.3390/fire6080325.
[30] D. Meißner, Auswertung von Unfallstatistiken von Elektrofahrzeugen in Bezug auf die Unfallursache: Arbeitspaket 2.2 Projekt ALBERO. https://alberoprojekt.de/index_htm_files/AP%202.2%20Auswertung%20von%20Unfallstatistiken%20von%20Elektrofahrzeugen%20in%20Bezug%20auf%20die%20Unfallursache.pdf (accessed 21 December 2023).
[31] M. Sundin, Fewer fires in electric cars compared to fossil-fueled cars (in the country with the highest share of electric cars), Warp News, 2023, 27 July, https://www.warpnews.org/transportation/fewer-fires-in-electric-cars-compared-to-fossil-fueled-cars-in-the-worlds-country-with-the-highest-share-of-electric-cars/.
[32] EPRI Storage Wiki, BESS Failure Event Database. https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database, 2023 (accessed 7 December 2023).
[33] BloombergNEF, Global Energy Storage Market to Grow 15-Fold by 2030 | BloombergNEF. https://about.bnef.com/blog/global-energy-storage-market-to-grow-15-fold-by-2030/, 2022. (Accessed 7 December 2023).
[34] C. Murray, Global BESS Deployments to Exceed 400GWh Annually by 2030, Says Rystad Energy, Energy-Storage.News, 15 June, 2023.
[35] Talkwalker, Social Listening für Consumer Intelligence. https://www.talkwalker.com/de/, 2023. (Accessed 8 December 2023).
[36] Neticle, Social Listening mit Neticle. https://neticle.com/mediaintelligence/de, 2023. (Accessed 8 December 2023).
[37] YouScan, Social Media Listening. https://youscan.io/, 2023 (accessed 8 December 2023).
[38] Landesbetrieb IT.NRW, Anzahl Wohnungen in Gebäude NRW. https://www.it.nrw/statistik/eckdaten/bestand-wohngebaeuden-und-wohnflaeche-nach-wohnungsanzahl-am-3112-533, 2023. (Accessed 7 December 2023).
[39] Statistisches Bundesamt Deutschland - GENESIS-Online, Wohngebäude Deutschland. https://www-genesis.destatis.de/genesis, 2023 (accessed 7 December 2023).
[40] G. Masson, I. Kaizuka, Trends in Photovoltaic Applications (2020) 2020.
[41] Bundesnetzagentur, Statistiken ausgewählter erneuerbarer Energieträger zur Stromerzeugung - September 2023, 2023.
[42] L. Aguilar, PV Solutions for the: Private Residential, Commercial & Industrial Sector in Germany, Berlin, 2019.
[43] J. Figgener, C. Hecht, D. Haberschusz, J. Bors, K.G. Spreuer, K.-P. Kairies, P. Stenzel, D.U. Sauer, The Development of Battery Storage Systems in Germany: A Market Review (Status 2023), 2022.
[44] A. Sepanski, F. Reil, V. Willi, H. Dr. Schmidt, G. Bopp, Guideline - Assessing Fire Risks in Photovoltaic Systems and Developing Safety Concepts for Risk Minimization, 2018.
[45] KBA, Der Fahrzeugbestand am 1. Januar 2023, 2023. https://www.kba.de/DE/Presse/Pressemitteilungen/Fahrzeugbestand/2023/pm08_fz_bestand_pm_komplett.html (accessed 21 December 2023).
[46] J. Hannay, The future of energy storage: batteries and beyond, Sustainable Future News, 2023, 5 July, https://sustainability-news.net/features/the-future-of-energy-storage-batteries-and-beyond/.
[47] ETAuto, LFP battery to retain dominant market share in energy storage sector - experts, Reuters (8 December 2023).
[48] T. Kaschub, P. Jochem, W. Fichtner, Solar energy storage in German households: profitability, load changes and flexibility, Energy Policy 98 (2016) 520–532, https://doi.org/10.1016/j.enpol.2016.09.017.
[49] C. Goebel, V. Cheng, H.-A. Jacobsen, Profitability of residential battery energy Storage combined with solar photovoltaics, Energies 10 (2017) 976, https://doi.org/10.3390/en10070976.