# Rapid expansion of roof mounted PV system installations in commercial facilities – How can they be insured?

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Abstract:
PV system components that are exposed to unmanageable strain can be overheated, which subsequently results in a fire ignition. Common failure factors are poor component quality, mechanical exposure due to natural phenomena and poor craftmanship. The underlying problem is that PV regulations are lacking in quality or are non-existent. The rapid expansion of roof mounted PV system installation on commercial facilities, therefore led to the question "How can they be insured?". This question was answered by the support of three research questions: "*What is known in the scientific literature and the insurance industry about PV component failures and installation errors over the last 10 years?"; "What challenges and gaps in regulations of PV components, systems and installations are found in the insurance industry and are they described in the scientific literature?"; "What changes in PV regulations and demands are expected to be seen in a near future*?" The research methodology consisted of a scoping study of scientific literature and a primary data collection performed as interviews with insurance company representatives. Relevant answers were provided, such as common component failures and recommendations for future insurance policies. The conclusion was that the development of new regulations that can be applied to the whole insurance industry relies on improvement of aspects such as definitions, technical understanding, and safety proactiveness. The implementation of these factors would make it easier for insurance companies to understand, assess and evaluate the risks related to a PV system. Consequently, when the underwriter is deciding on a premium, the pricing will be in line with the risk spectrum. This would preserve the risk appetite for future insurance policies.



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# Table of contents

**List of figures:**



**List of tables:**

**List of appendices:**

Appendix 1: Interview formalities

Appendix 2: Interview questions

Appendix 3: Interview Log and transcript

Appendix 4: Email correspondence

**List of acronyms:**

**AC:** Alternating Current

**EAR:** Erection All Risk

**EML:** Estimated Maximum Loss

**EU:** European Union

**CAR:** Construction All Risk

**DC:** Direct Current

**FPA:** Free of Particular Average

**IBC:** International Building Code

**IEA:** International Energy Agency

**IEC:** International Electrotechnical Commission

**LPS:** Loss Prevention Standard

**MCS:** Microgeneration Certification Scheme

**NFPA:** National Fire Protection Association

**PEF:** Product Environmental Footprint

**PML:** Probable Maximum Loss

**PV:** Photovoltaic

**PVS:** Photovoltaic System

**SBF:** "Svenska brandskyddsföreningen" (the Swedish Fire Protection Association)

**UL:** Underwriters Laboratories

**UW:** Underwriter/Underwriting

# 1. Introduction

## 1.1. Rationale & research aim

The use of solar energy has become an attractive approach to reduce costs and become more environmentally friendly. The photovoltaic (PV) system market has therefore become well-known among commercial businesses. Apart from the many advantages, the technique involves several critical points and hazards. One core issue is that PV systems always remain energised, which consequently means a risk for electric arcs (Sepanski, 2018, p. 8). From a stakeholder perspective, a failing PV system is an inconvenience and subsequently a danger for many. From a commercial-insurance perspective, there is generally an issue how to assess this relatively new risk.

A major difficulty with PV is the lack of uniformity in international compliance for codes and standards. The absence of global standards and tests, implies each country to perform their own quality tests. This is neither economical or time persevering and will not be justifiable in the long run (Sarkar, 2021, p. 1278). The lack of uniformity in code and standard compliance, means that manufacturers make products that are adapted to different markets, which in the long time-perspective increases the product costs, simultaneously as the quality testing will deteriotate. Lack of codes and standards in PV also has negative impact on personal safety, such as for operating firefighters, since the hazard characteristics of a failing PV component might be unknown (Ibid., p.1278).

The insurance broker, Aon who are providing risk consulting services on worldwide level have seen this trend as worrying for future insurance policies. As an intermediary for the client and the insurance company, Aon was interested to sort out the main issues in terms of individual component malfunctions, system failure and installation errors. Since time and resource management was a limitation, the task was assigned as a research project for a master thesis.

The research aim of the thesis is to: *increase the knowledge about present and future issues regarding PV systems and how it affects the insurance industry*. The research questions and objectives are presented below.

## 1.2. Research questions & objectives

The objective of the thesis was to do a systematic literature study and a primary data collection using interviews regarding the insurance issue with PV systems. The literature studies consisted of a scoping technique with a selection of research questions as basis. Keywords have been used to identify relevant studies that later have been extracted to further chart the data. Thereafter, the data has been compilated and categorised to draw conclusions. The primary data collection was executed by interviewing representatives from various insurance companies. Before the interviews, a questionnaire was sent out in advance. When all interviews were completed, a compilation of the answers was made to draw conclusions.

***Research questions:***

1. *What is known in the scientific literature and the insurance industry about PV component failures and installation errors over the last 10 years?*
2. *What challenges and gaps in regulations of PV components, systems and installations are found in the insurance industry and are they described in the scientific literature?*
3. *What changes in PV regulations and demands are expected to be seen in a near future?*

# 2. Background

## 2.1. The development of commercial roof mounted PV systems

The development of PV systems in construction is a significant trend all over the world. It has been a rapid expansion of usage in the business area. The manufacturing industry is continuously developing, and new solutions are implemented regularly. Worldwide, it has become a commitment to find productive and efficient methods for producing energy. The present focus is towards finding the best renewable energy sources that can operate efficiently, reduce the consuming costs, and contribute to the green transition (Ying-Yi & A.Pula, 2022).

PV systems have been used more frequently since the energy crisis in the early 1970´s (Ong & Tohir, 2021). In the aftermath of that period, the demand for renewable energy and more specifically, solar energy, has increased dramatically. The interest and demand for PV systems in commercial purposes has also increased as special agreements, such as the Kyoto protocol and the Paris agreement, systematically have been established and entered into force (Ying-Yi & A.Pula, 2022). The International Energy Agency (IEA) estimates that, before 2040, the world's demand for energy will significantly rise at a rate of 2.1 % per year. In Germany, it was determined that the output from solar power plants grew by more than 60 % annually from 2007 to 2010 (Ibid.).

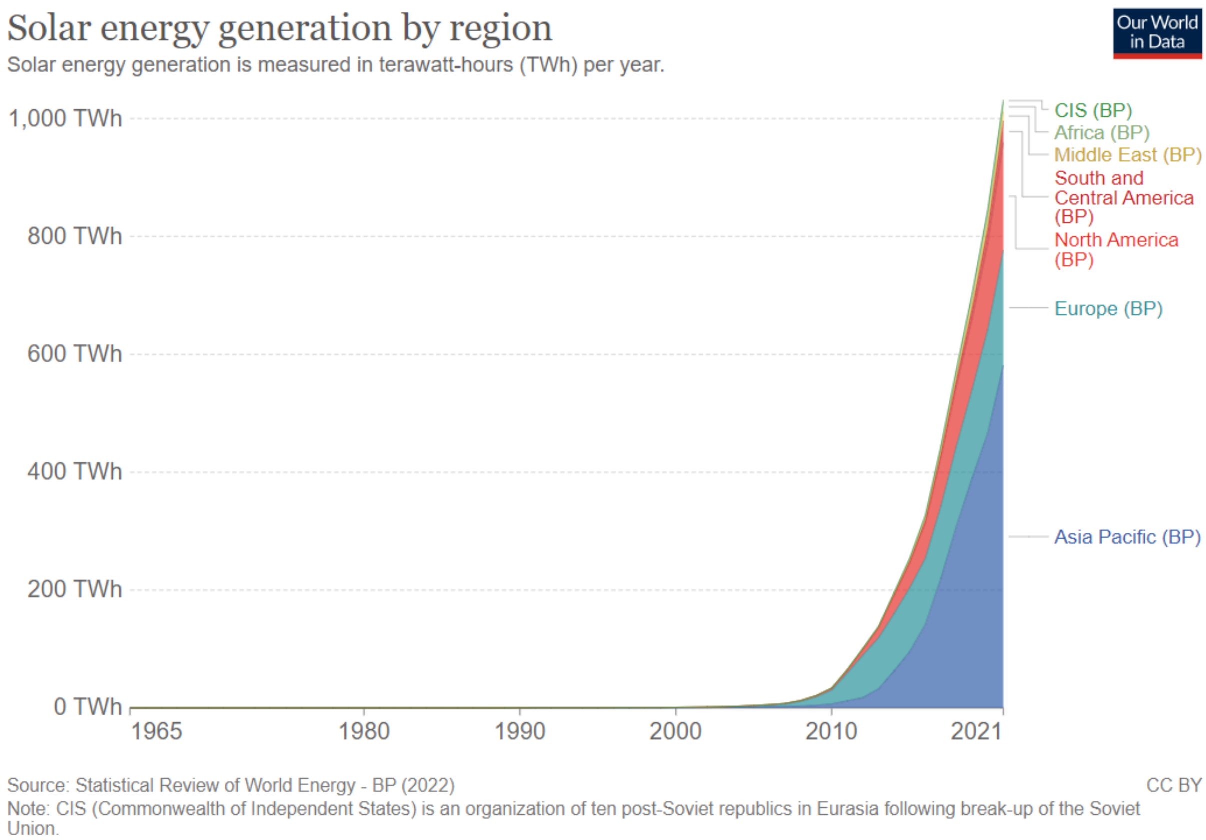


*Figure 1:* Solar energy generation by region, Our World In Data, 2020, https://commons.wikimedia.org/wiki/File:Solar_energy_generation_by_region,_OWID.svg, CC BY-SA 4.0)

### 2.1.1. Arguments & incentives for installation

Electricity is presently produced using a variety of different power sources. From a worldview perspective, the most used sources are still the conventional thermal power, represented by coal, oil, and has gas-fired power plants. Since these power plants are contributing to carbon dioxide emissions and are finite resources, the focus has been directed to green transition solutions (Ong & Tohir, 2021).

**Effectiveness of solar power**

The first commercial PV application was in 1954 at Bell Laboratories where the researchers used a silicon solar cell to power up small toys and radio transmitters. The thermal radiation that was converted to applicable electricity suppliance reached about 6 % in efficiency (Chodos, 2009). That was a great achievement since that efficiency rate had never been reached before.

Today, there is a variety of materials that are available for making PV modules. In addition to the standard monocrystalline silicon modules, there are multicrystalline silicon modules, multi-junction gallium arsenide modules, etc (Center for sustainable systems - University of Michigan, 2022). These modern module solutions do not only come in different materials, but also have a considerable increase in conversion efficiency. On average, a modern monocrystalline silicon module is now able to convert thermal radiation into electricity with approximately 20 % efficiency. A gallium arsenide module can efficiently convert the thermal radiation into electricity with almost 40 %. Generally, this a gallium arsenide module is less common than silicon since the mining and manufacturing cost is substantially higher (Ibid.).

**Cost-effectiveness & green transition**

Commercial PV systems are often used to reduce the energy costs in the production facility. Cost-effectiveness is therefore a critical point for the client when validating whether a PV system installation is a good investment or not. Since the overall efficiency of crystalline modules have been increased, the earning period regularly starts sooner than before, and the investment pays off quicker. Also, the installation as well as the component costs have been successively lowered as the competitive market has started to grow due to higher demand (Center for sustainable systems - University of Michigan, 2022).

Discovering new ways of producing green energy is a major priority in the energy sector. Modern PV system are taking an approach where the green transition is put to a further extent. In a modern PV system that eventually will be retired, there will be intact and functioning components that are possible to reuse (Center for sustainable systems - University of Michigan, 2022). Components such as multicrystalline modules can be reused by over 50 %. It is said that pollutions and toxic substances that come with production will be shadowed by the low emissions that comes during a commercial PV system's life cycle. Moreover, the energy performance for a commercial PV system has been proven to be generating from three up to six times the energy that is required to manufacture and install one.  The energy performance, measured as price per watt, in relation to the cumulative installed solar PV capacity has been measured and extrapolated, see figure 2. The trend shows that the PV modules tend to drop in price with approximately 20 % for every reduplication and with almost 50 % for every 10th module shipment increase (Ibid.).

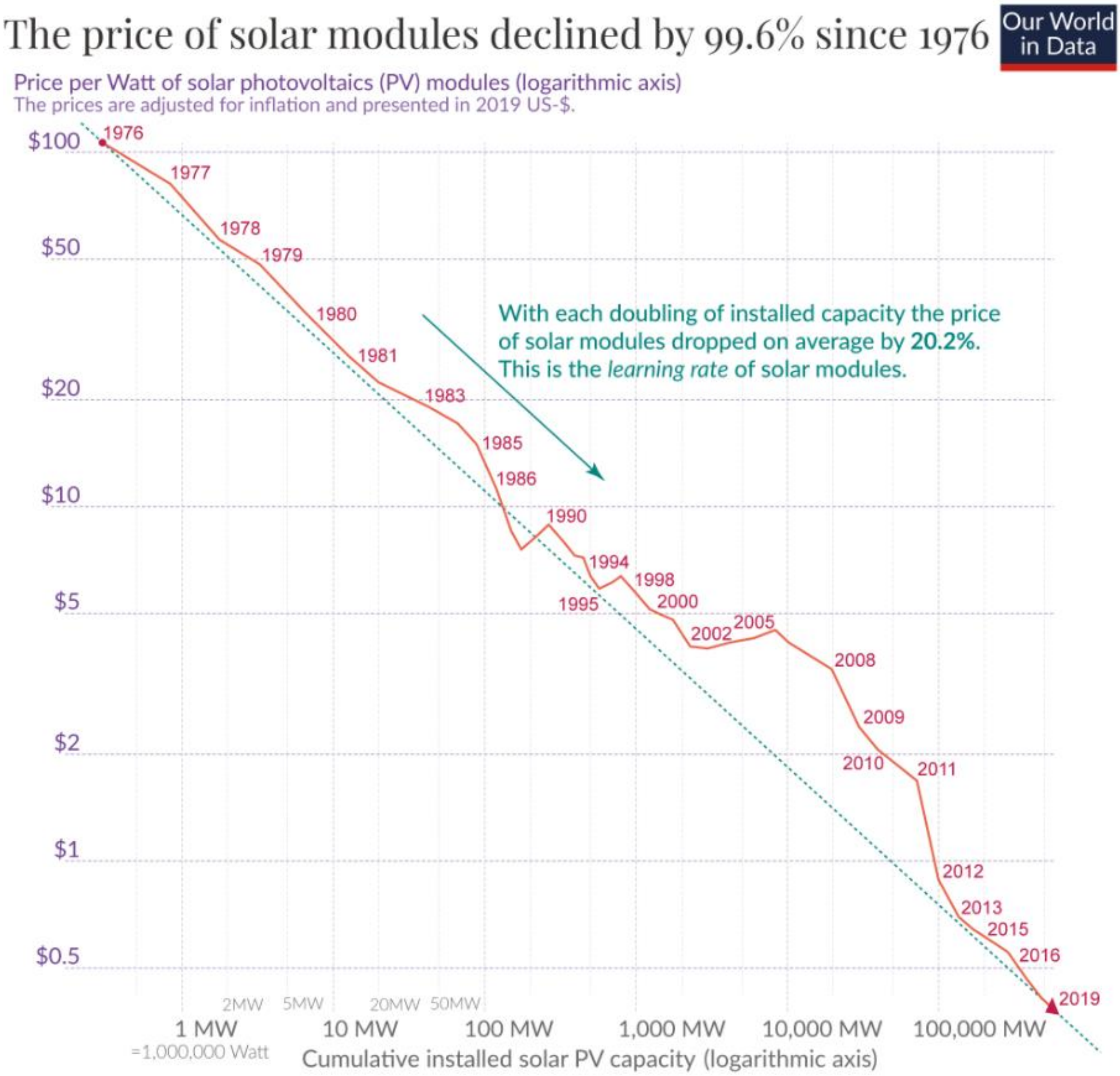


*Figure 2:* Solar-PV-Prices-vs-cumulative-capacity, Our World In Data, 2020, https://commons.wikimedia.org/wiki/File:Solar-pv-prices-vs-cumulative-capacity.png, CC BY-SA 4.0)

## 2.2. Commercial PV systems & insurance

In most cases, commercial PV systems operate under mild and smooth circumstances where the damages are either non-existent or fractional. However, there are various problems that in many ways are problematic for either the client, insurance company or both. A typical fault is the component misplacement and poor execution of installations. Any misplacement or installation fault can result in unfortunate events, such as fires that can hurt people and the environment. It is not only fires that are problematic, but also machine defects or prototype errors that causes delays in production (Buzio & Stuart, 2022).

From an insurance perspective, this is a disturbing tendency. The evolution of PV systems proceeds so fast that the knowledge within the insurance industry cannot catch up. Since there are lack of regulations for risk engineers and underwriters to evaluate the risks, many of these commercial installations cannot be insured in a good way. This has negative effects on several levels (Schwab et al., 2020, pp. 27-28). On a client level, the risk evaluation can become either over- or underestimated due to lack of regulations, but also since the competence of the risk engineer is not in line with product development. For the client, this becomes a question of premium levels, whether they are pessimistically set or not. For insurance companies, lack of regulations along with lacking competence in the product development makes it difficult to insure industrial facilities. Without guidance and competence, less insurance coverages can be offered, which consequently means less clients and therefore less income. On a long-term perspective, this could have an inhibitory effect on the desire to invest in commercial PV system solutions and negative effects on the environment.

### 2.2.1. Technical risks & product development

It has been clarified that most of the issues regarding commercial PV systems are related to errors in components within the system or due to poor workmanship. PV systems come in various designs and approaches depending on the product, workmen and the facility design itself. It is not the variety of settings, but the technical components themselves and what building materials they are attached to that brings issues. It is also proven from studies that fire incidents involving PV systems specifically highlight the defect of components as 33 % of total damage cases, along with 33 % of deficient planning and the faulty installations as 33 % (Sepanski, 2018, s. 12).

Technical risks imply economical risks for an insurance company. The technical investigation is a major part when the risk engineers are performing their field inspections. If there are obvious faults, such as poor workmanship regarding the mounting of components or the PV arrays are attached directly to a combustible roof, then it is easier for the risk engineer to validate the facility installation. In other situations, where it might not be obvious to observe and confirm the hazards, there are several uncertainties that must be assessed to evaluate the risk situation (Sepanski, 2018, p. 12).

There are several manufacturers across the world, most being established in China. These manufacturers are producing their own set of components belonging to a specific kind of PV system. This creates a market competition, where some components are less expensive than others. Consequently, many clients get a set of PV system components from various manufacturers. As a result, it leads to a mismatch fault between components. One common fault among components is the connectors mismatch. Normally, this means different resistance in the connectors, which means that different amount of current is allowed to pass through the component. Too much current in one of the connectors will therefore result in overheating, subsequently leading to an ignition which can initiate a fire (Ying-Yi & A.Pula, 2022, pp. 5902-5903).

### 2.2.2. Codes, standards & legislation

For every technical component or system there is usually a manual and a safety regulation book. What has been concluded regarding the PV system documentation, is that it often contains insufficient or barely any information about the hazards that comes with the system. This is problematic situation in terms of ambiguity in the individual scenario, specifically devised for a PV system. On a larger scale, there must be standards and codes that are founded in legislation that are understandable and comprehensive. In some countries, such as in Germany, there are standards for low-voltage systems known as DIN VDE 0100, which is based on the European Low-Voltage Directive (Sepanski, 2018, pp. 12-15). Most standards for PV systems installed in Germany are compiled in the DIN VDE 0126 series.  Germany also has an institute that has published a list of instructions for assembling and installing PV systems in relation to present building criteria. Even though, there are countries that have better improved standards for commercial PV system installations, there is dissonance across the continents on how to validate (Ibid., pp. 12-15).

# 3. Research methodology

For this research, there have been two main methods for collecting and analysing data. As a part of an inductive logic of inquiry, a qualitative as well as a quantitative approach have been applied, performed by a scoping study and primary data collection represented by interviews respectively.

## 3.1. Scoping study

The scoping study consisted of a systematic literature study, including scientific literature and previously documented events with PV systems that had a negative outcome, caught fire, damaged industrial inventories etc. It was also used to identify present regulations regarding the insurance conditions for installed PV systems.

### 3.1.1. Definition of a scoping study

The scoping technique is not distinct or precise in its definition. Still, there are checkpoints and other guiding references that are incorporated within the methodology. Crucial checkpoints to consider are listed and cited below.

- “To examine the extent, range, and nature of research activity”
- “To determine the value of undertaking a full systematic review”
- “To summarise and disseminate research findings”
- “To identify research gaps in the existing literature”

(Allen, 2001, pp. 188-220).

### 3.1.2. Identifying the research questions

Developing scientific research questions was the initial step before starting the scoping study. That meant a strategy where data was searched broadly to minimise the risk of unintentionally miss any relevant articles (Arksey & O'Malley, 2005, pp. 19-32). Simultaneously, there was a difficulty to find a manageable amount of relevant data. The accessible data regarding the subject insurance of commercial PV system was not particularly broad. Still, there was substantial amount of data about the damaging effect caused by a PV system. Overall, commercial PV systems in relation to complex insurance questions is a relatively new phenomenon which consequently meant that a wide approach had to be taken to generate breadth of coverage. Therefore, the research question was oriented towards embracing everything that was relevant from an insurance perspective, such as the characteristics of PV component failures, regulations for PV installation and the assessment of risks related to PV. The researcher ended up with following research question: *"What is known in the scientific literature about insurance of commercial roof mounted PV systems?"*

Starting up the research meant searching widely on keywords that were relevant to the subject regarding commercial PV systems. The objective of that approach was to find out and make sure that there was a decent amount of scientific literature to be found that suited the terminology and the claim of relevant information (Josef, 2016, pp. 413-446).

### 3.1.3. Identifying relevant data

The initial approach was searching for reports and other scientific articles on electronic databases. Publications that could be extracted through Lund University licence were used. A search query identification was done to find relevant keywords that were closely related to the research question (Josef, 2016, pp. 413-446).

**Use of databases**

The database Scopus was used. Scopus is known for providing reports that are peer-reviewed and multi-disciplinary (Josef, 2016, p. 413-446). In addition, to embrace the data that was not accessible through the traditional publishing and distribution forums, a grey literature study was done using Google as search motor.

**Search query identification**

The search string was based on a Boolean approach. The keywords represented by the research questions were: (1) PV system fires, (2) PV component failures, (3) PV regulations, (4) future PV regulations, (5) PV risk assessment, (6) PV risk evaluation and (7) PV insurance price. On a stand-alone basis, these keywords were not enough to cover all relevant data and so too insufficient (Josef, 2016). To increase the search, a list of similar words was compiled by searching on similar concepts. These similar words were systematically combined and separated when performing the searches. For every search, the number of results was noted for each query. Irrelevant and duplicate data were removed. By combining the following and searching the titles, abstracts and keywords, most data was found:

(A) Fire OR hazard OR risk
(B) Failure OR collapse OR degradation OR fault
(C) Regulations OR legislations OR jurisdictions OR codes OR standards OR demands OR requirements
(D) Insurance policy OR insurance cost OR premium level

Figure 3 illustrates the number of results in a search string.

### 3.1.4. Study selection

Articles that did not refer to commercial PV systems were directly removed from further analysis. Since the interest was towards examining roof mounted PV systems, the articles that did not cover these were automatically sieved away.

**Prerequisites & criteria for data selection**

The selection of data was conducted by sorting out certain concepts. The search consisted of the following inclusion criteria:

1) Published articles are in English
2) Published articles are peer-reviewed
3) Published articles in subscribed journals

4) Age of articles < 10 years

In addition to the inclusion criteria, a title and an abstract analysis were made. Titles that clearly did not match the keywords or did not have a relevant touch and direction on the topic of the thesis research were excluded. Similarly, abstracts that mentioned relevant words, but did not cover or highlight the relevance of the thesis's aim or research questions were excluded for further analysis and use. Subsequently, with the use of inclusion criteria and exclusion of duplicates etc.  7 articles were left to be used as reference material, see figure 3.

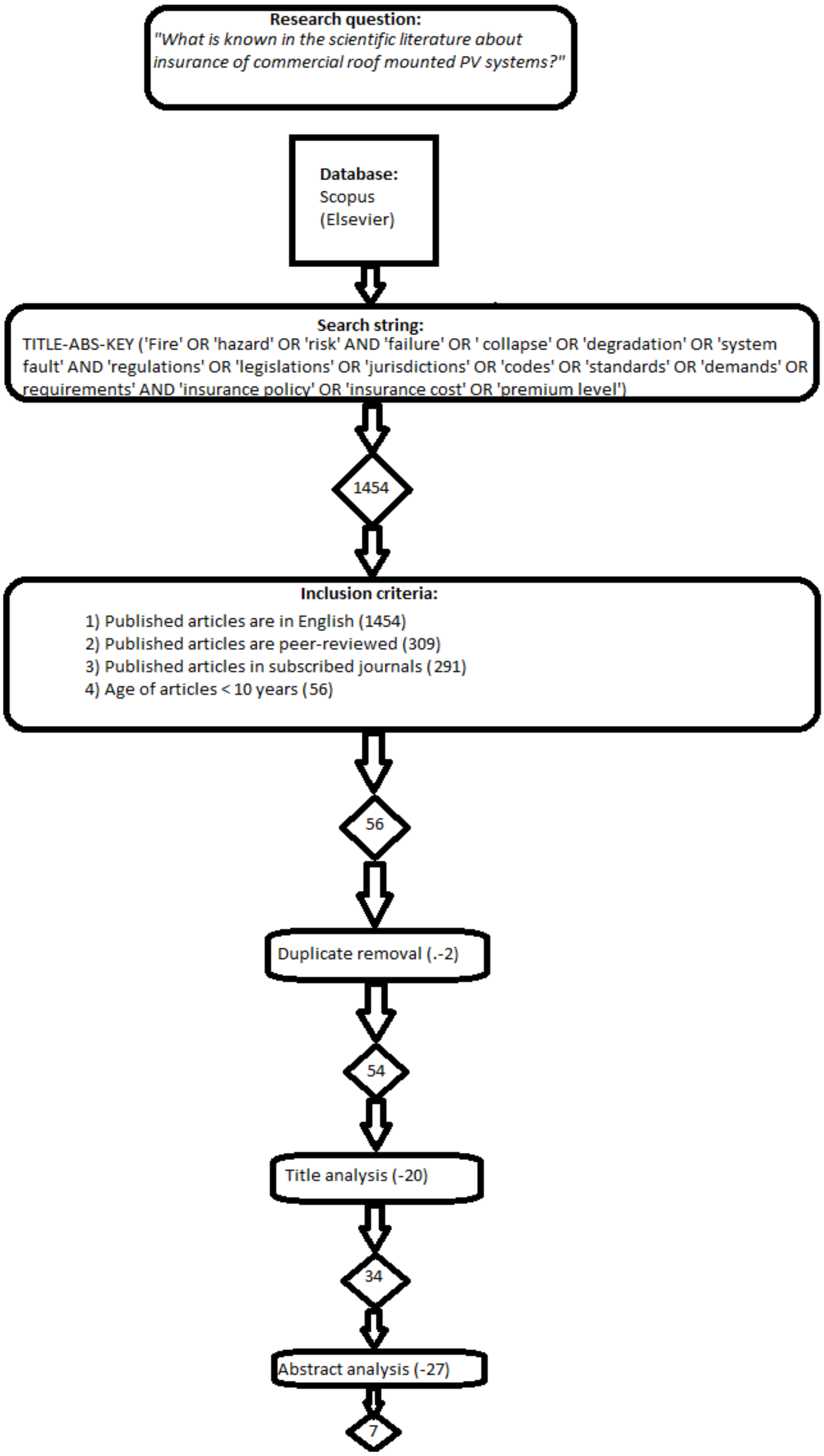


*Figure 3*: Overview of the scoping study method.

### 3.1.5. Use of grey literature

The accessible material that was extracted from the database covered major parts for analysis. It was not considered enough to cover all necessary details. This was a direct effect of the pre-decided prerequisites and criteria for the scoping study, with explicitly mentioned concepts and terms. To not lose any other relevant scientific sources, a grey literature analysis was performed by using the Google search engine. The researcher ended up with following research question: *"What is known in the scientific grey literature about insurance of commercial roof mounted PV systems?"*

**Prerequisites & criteria for data selection**

The selection of data was conducted by sorting out certain concepts. In similarity with the scientific literature analysis, the Boolean approach was applied. In addition, the search consisted of the following inclusion criteria:

1) Scientific data not older than 10 years
2) PDF as main file type
3) Only reports, webpages, and documents from webpages
4) No PowerPoints or product information sheets

Unlike the scientific literature search, an overview of the search was not manageable due to the massive number of search matches. Some searches, considering all criteria, resulted in millions of hits. Given the conditions of time and resources, a selection had to be made, which meant that only "first page-matches" were used.

### 3.1.6. Limitations of the scoping study

The major limitation when performing the scoping study was to find a decent amount of data that could be used to cover the delicate balance regarding breadth and depth. This is also highlighted as a key factor for a successful scoping study (Arksey & O'Malley, 2005). The narrow spectrum of relevant scientific articles made this a challenge. By using a wide question about what is known in the scientific literature, the author expected the outcome of the scoping study to generate a generous number of relevant articles. Instead, the number of articles was considerably low. Several articles were sorted out from the abstract filtration. The most common reason was that the articles covered ground mounted PV systems, not roof mounted PV systems. Further, several articles regarded private use, not commercial. Ultimately, this meant that several articles that were relevant according to the titles, became irrelevant due to the content of the abstracts.

In addition, there was a limited number of clarifications in terms of figures, tables, and photos to be used for further argument development. This was both due to the limitation that insurance of commercial roof mounted PV systems are yet a considerably new framework, but also due to the copyright issue.

Limited amount of time and access to data could not be unnoticed. Since there was a limited amount of data to be extracted, the depth of the research was responding to what data and material that was accessible and useful. This was mainly a pronounced issue due to the unmanageable number of matches in the grey literature searching. A scoping study was therefore a suitable way of dealing with that issue, since the aim and focus of a scoping study is to identify key concepts and investigate patterns and trends that have not been reviewed comprehensively before (Allen, 2001, pp. 188-220).

## 3.2. Primary data collection – Interviews

As the second part of the thesis research, a primary data collection was done by performing interviews with representatives from various insurance companies. It was requested by the collaboration company, Aon to specifically ask representatives that were working as risk engineers/underwriters at the insurance companies since they are working closest to insurance complexities of facilities with roof mounted PV systems. There was different amount of experience within the subject between the respondents. When all interviews were performed, conclusions were drawn based on the combined result of answers from all respondents.

Before the interview, the participants were asked to read through a form, which consisted of the questions that were about to be asked during the interview. The idea of this initiative was to ensure that the participants could enter the interview as prepared and open for reflection.

### 3.2.1. Identifying research questions

To confirm or contradict the findings from the scoping study, representatives from various insurance companies were asked to answer a selection of questions regarding the common faults in commercial PV systems and the insurance possibilities. In conformity with the scoping study, the interviews indicated similar qualitative results. Furthermore, since the interviews had several angles of incidence, it also served a quantitative purpose, which strengthened the qualitative findings from the scoping study as well as revealing details about present complexities in operative risk assessment and future underwriting. In that aspect, the interviews were essential to present what the most trending component faults and what the regulatory tools were in PV installations when performing a facility inspection.

### 3.2.2. Study selection

For the interviews, some of Sweden's largest insurance companies were asked to participate, representing almost 75 % of Sweden's total commercial property insurance market share over the last three years. In addition, the representatives were carefully selected using purposive sampling. The collaboration company, Aon and the thesis author specifically asked the insurance companies for experienced risk engineers/underwriters to share their experiences and future thoughts on the subject. Employees who did not have the adequate experience, were therefore not asked to participate in the thesis research.

To get a representative image of the global situation, an essential condition was to include insurance companies that operates internationally. Therefore, the largest insurance companies by the present market cap were asked to participate. Furthermore, the idea was to include companies that were specialised in commercial property claims, both in direct insurance and reinsurance. In total, eight representative companies were requested to participate, where six of these accepted to take part in the research. Within the respondent group, there was wide range of different professions, such as risk engineers, underwriters, account engineers and risk managers. After completing the interviews, it was assessed that the variation of respondent answers was not particularly widespread. With that reasoning, no further reach out was made with other insurance companies or representatives from the already interviewed companies. The result from the existing number of participants was considered to have reached data saturation. Therefore, adding one or two more companies to the research was not considered to be necessary for the end result.

### 3.2.3. Interview technique & data analysis

Structured interviews were performed as the method for data collection. For this, a strict questionnaire was used for all interviews. The objective was to get a result that was comparable and with good accuracy. The answers from the respondents were used as basis for answering the research questions. All respondent answers were anonymised.

*Table 1*: Questionnaire for respondents.

| ***Question*** | | ***Alternatives*** | ***Free answer*** |
|---|---|---|---|
| 1. Over the last 10 years, what experiences do you and your company have regarding the characteristics and trends of solar panel fires? | | (Free answer) | |
| 2. Based on your and your company's experiences, what is/are the most common factor(s) that have led to PV system fire accidents? Rang from 1-7, where "1" is least and "7" is most common. | | Installation errors<br>Poor quality of PV arrays (material imperfection, fabrication flaws, etc.)<br>DC arc ignition<br>Hot-spot effect (partial shading of cell)<br>Damage caused intentionally (sabotage, vandalism, etc.)<br>External influence (snow, wind, temperature, etc.)<br>Battery failure | |
| 3. What type(s) of insurance coverage(s) do you offer to an industrial customer when it concerns a PV system? | | CAR/EAR (Construction or Erection All Risk)<br>Property Insurance<br>Other | |
| How does your company evaluate risks for industrial premises with PV systems? | Follow up on question 4: If your answer was "Neither/Other", Describe how your company evaluates risks when insuring PV systems? | Probable Maximum Loss (PML)/Estimated Maximum Loss (EML)<br>Maximum Foreseeable Loss (MFL)<br>Normal Loss Expectancy (NLE)<br>Neither/Other | (Free answer) |
| 5. What regulations and jurisdictions are used within your company when insuring PV systems? | | (Free answer) | |
| 6. Does your company use any specific regulations/demands for the battery that is connected to the PV system? | Follow up on question 6: If your answer was "Yes", Describe the specific regulations for a battery that is connected to the PV system? | Yes<br>No | (Free answer) |
| 7. From your personal and your company's view, are the regulations and jurisdictions clear and easy to comprehend and implement? | Follow up on question 7: If your answer was "No", Describe the difficulties, uncertainties, etc. about the regulations and jurisdictions that you and your company are using. | Yes<br>No | (Free answer) |
| 8. In your opinion, what necessary regulations/jurisdictions must be founded to better insure PV systems? | | (Free answer) | |
| 9. Do you or your company find any other problems that come with the high price on the insurance coverage for PV systems? | Follow up on question 9: If your answer was "Yes", Describe the other problem(s) that you or your company find with the high price on the insurance | Yes<br>No | (Free answer) |

| | | | |
|---|---|---|---|
| | coverage for PV systems. | | |
| 10. Does your company change attitude and willingness to insure after finding out there is a PV system involved? | Follow up on question 10:<br>If your answer was "Yes", Describe how it changes the attitude to insure. | Yes<br>No | (Free answer) |
| 11. Is there anything that you want to add or feel is missing? | | (Free answer) | |

### 3.2.5. Limitations of the primary data collection

Coordinating and scheduling suitable time slots for the interviews was the initial limitation when aiming for a time-effective process. Time slots were flexibly offered from early in February to late in March. Since the interviews were performed in around two months, it resulted in a relatively protracted process, were the results and trends took longer time to be clarified than initially expected. Fortunately, the delay of the interviews results was managed by focusing on the scoping study.

Another limitation was the lack of comprehensive knowledge in the field of PV technology and issues seen in the insurance industry. At the time when the questionnaire was sent out to the respondents, the knowledge in the field was yet not as developed as it later turned into. A broader knowledge at that time could have been beneficial to ask more precise and target-oriented questions, specifically regarding the more "open" kind of questions.

# 4. Result compilation

## 4.1. Answering research question 1

To answer the first research question, “*What is known in the scientific literature and the insurance industry about PV component failures and installation errors over the last 10 years?”*, a holistic approach was taken using the scoping study and the primary data collection.

### 4.1.1. Access to relevant data

The accessibility to relevant data was satisfying and rewarding in several aspects. From the scoping study, most data that were used was represented by larger PV-pioneer countries from different continents, such as the United States, Australia, and Germany. The search for scientific literature in the database resulted in a considerably low number of articles. From a data access perspective, this was a limitation since it could affect the scientific credibility of the thesis research. Simultaneously, it could prove that the published knowledge in the scientific literature was yet to be discovered and written about.

From the interviews, there was a broad consensus on the fault occurrences, but also on the overall reasoning about future challenges.

### 4.1.2. Scoping study: General observations

**<u>General characteristics and trends over the last 10 years</u>**

Since the first occurrence of PV systems in the beginning of the 1970, the technology has been evolving rapidly. The technology is rather young compared to other power sources, such as oil, gas, and coal, but still, there have been a massive development and improvement when it comes to quality, efficiency, and reliability. Much have been achieved by the openness and willingness to invest in green transition-solutions. Additionally, more testing and inventing has been done to make the systems better (Ong & Tohir, 2021).

One of the major findings is that the increased demand for PV systems has led to a reduction in overall quality (Center for sustainable systems - University of Michigan, 2022). The reason is that clients validate the price more than the actual quality of the system. In other words, many system installations are focused on keeping a certain price point rather than providing a robust and persistent system that will operate for a long time. In addition, another observed trend was that batteries and inverters that are connected to the PV system often are miscalculated in capacity size due to the investors idea of minimising the investment cost.

Another observation was the problem with loose connections between wires and attachments. Loose connections can cause DC arc ignitions that can damage either some parts of the surrounding construction or lead to a full-scale fire if igniting highly flammable materials. (Sepanski, 2018, pp. 39-43).

## Description of components in a representative commercial PV system

A modern PV system is a complex assembly of many different components that are necessary for the system to work efficiently and safely. Every component represents a specific role, where several components are dependent on each other’s function.

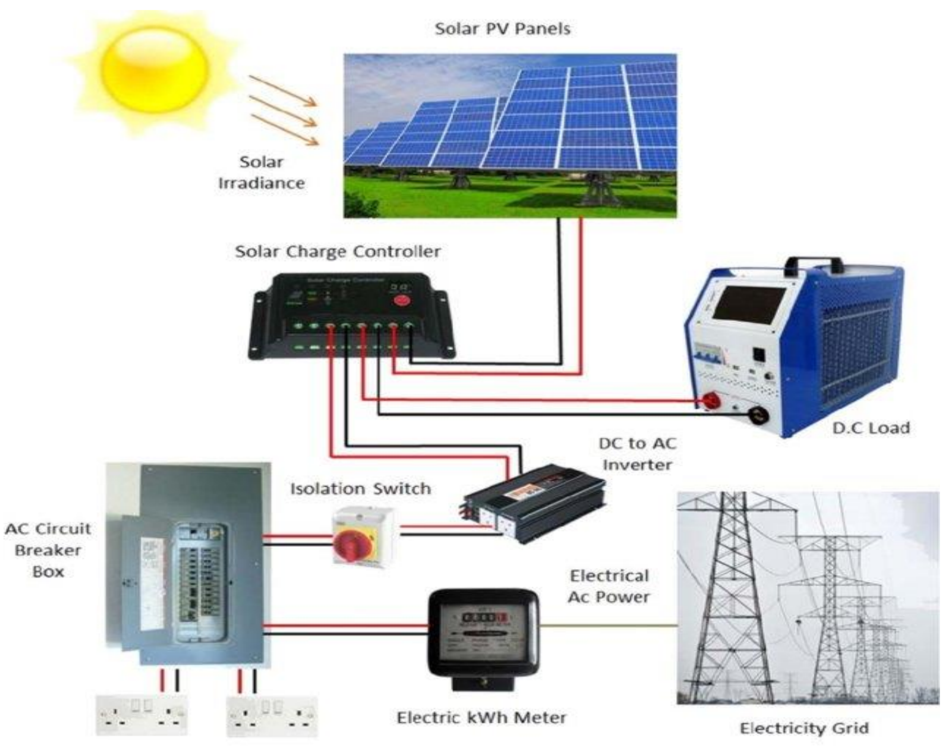


*Figure 4:* A block diagram showing the grid-connected PV system with a battery backup, Fadhil Khadoum Al Housni, 2022https://www.researchgate.net/figure/A-block-diagram-showing-the-grid-connected-PV-system-with-battery-backup-39_fig2_362262438, CC BY-SA 4.0.

**PV cell, PV module & PV array**

***Description of function & operative use***

A PV cell is dominantly made by silicon crystalline. Cells vary in size, shape, and type. The normal size cell is usually capable of producing 0.5 volts. Previous generations of cells were shaped more towards the circular shape, while modern generations are manufactured towards the octagonal appearance. Even if the change of appearance resulted in less efficiency per cell, the material preservation improved as the previous generations incorporated more material loss (Franklin, 2018, p. 1)

By adding multiple strings of cells that are wired in series, a module is created. The size of a module varies, but a 36-cell module approximately produces around 18 volts. The size of an individual cell or the number of cells in a module determines the amount of amperage. When adding several modules by wiring them together in series from negative to positive, an array is made. When connecting a series of modules into an array the voltage is added, meaning that the ability to transport of electrons improves. However, the current stays on the previous level (FSEC, 2023).

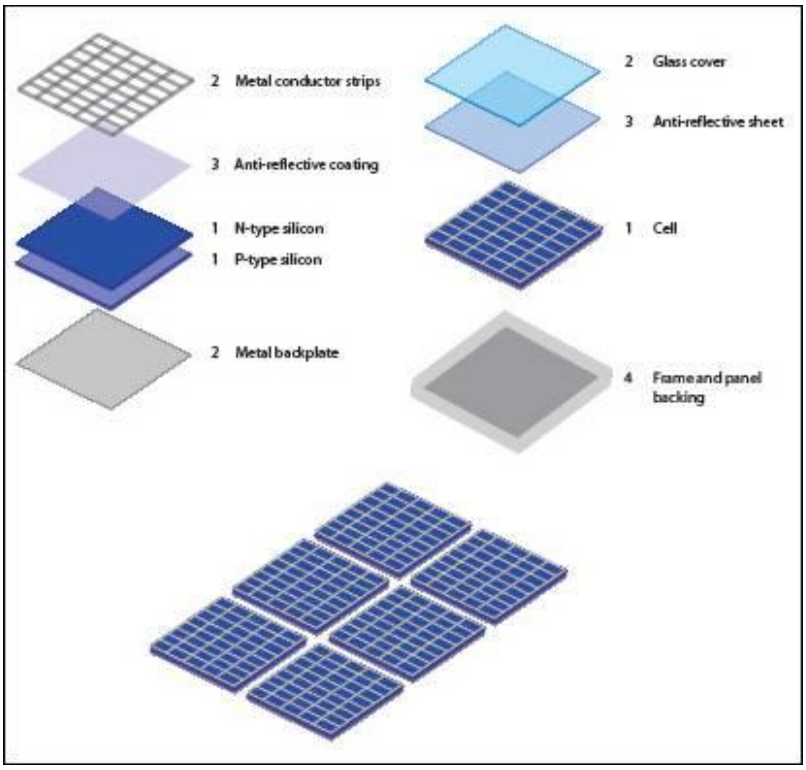


*Figure 5:* Layers of solar panel, Wmwnebvr97, 2015, https://commons.wikimedia.org/wiki/File:Layers_of_solar_panel.jpg, CC BY-SA 4.0.

*Description of dysfunction & operative failure*

Since a PV module is a multi-layer component there is several potential inconveniences that can cause dysfunction and operative failure. In the scientific literature, there were 17 types reported failures that were directly related to module failure. Modern PV modules are most exposed to shading, also known as the hot-spot effect, where certain parts of the module are covered causing overheating. On previous modules, encapsulant discoloration and cell cracks were common faults (Akram, 2022, p.33).

## MC4 connector

*Description of function & operative use*

The absorbed solar energy that is extracted from the modules into DC travels through several links before it is transmitted into AC. A safe electricity travel from the modules to this point is therefore of great value. Connectors operate to maintain a low resistance so that the current flow maintains constant through the transmissions. Simultaneously, it is supposed to prevent any sudden and unexpected change of voltage (Pickerel, 2015 ).


*Figure 6:* MC4 connector, Multi-Contact AG, 2013, https://commons.wikimedia.org/wiki/File:MC4_connector.jpg, CC BY-SA 3.0.

### *Description of dysfunction & operative failure*

Connectors are usually manufactured and assembled in a factory, but sometimes they are assembled in the field. Field-assembled connectors tend to not be mated together correctly, which enables water to penetrate the inside of the connectors. The water leakage in combination with high current causes electrical failures that often results in spark ignition that subsequently initiates a fire (Pickerel, 2015 ).

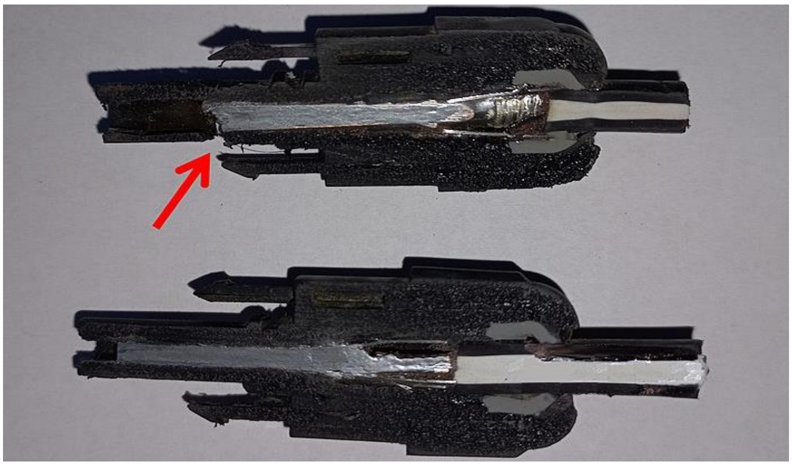

*Figure 7:* MC4-plug damage-13ASD, Asurnipal, 2021, https://commons.wikimedia.org/wiki/File:MC4-plug_damage-13ASD.jpg , CC BY-SA 4.0.

## **DC combiner box**

### *Description of function & operative use*

PV systems on commercial facilities tend to have several arrays. Each array has an individual solar string that must be transferred into a common solar string before the electricity can be converted from DC to AC (Franklin, 2018, pp. 2-3). Each array has several modules with positive and negative leads that are connected to an individual fuse and a negative busbar in an enclosure respectively. To add the voltage and maintain the current, these independent string series must be consolidated into a common parallel circuit. For this, a DC combiner box is used. A DC combiner box also has a protective and reliability purpose since it controls the threat of overvoltage and overcurrent.

*Figure 8:* Hard-Schulde am See PV-Anlage-WR-02, Asurnipal, 2018, https://commons.wikimedia.org/wiki/File:Hard-Schule_am_See_PV-Anlage-WR-02.jpg, CC BY-SA 4.0.

*Figure 9:* Solar combiner box, cocreatr, 2011, https://commons.wikimedia.org/wiki/File:Solar_combiner_box.jpg , CC BY-SA 2.0.

### *Description of dysfunction & operative failure*

A malfunctioning combiner box can cause problems with conversion of electricity from DC to AC. Most common problems that are related to the combiner box are leaks and loose connections. Loose connections easily result in an electrical failure involving flames and smoke (Smalley, 2015).

## DC isolator switch

### *Description of function & operative use*

There are times when the DC must be switched off to de-energize the array and make sure that the inverter is safely isolated from the power source. This can either pass manually when the owner decides to turn off the facility because of various reasons (e.g., energy-storage circuits) or since there is an issue regarding the system earthing (Sepanski, 2018, pp. 90-93).

Breaking DC is a critical operation since the current does not have any voltage zero points. This means that the voltage must be artificially forced to reach this point. Consequently, a complete current stop is not achieved immediately. Instead, there is an overlap-period where there is a light arc between the switch contacts that first reaches a high temperature and a high voltage. It is a challenge to break the DC since it incorporates high arc temperatures and arc conductance along with high voltage over the isolator switch. In commercial PV systems, it is important to make sure that the isolator switch can sufficiently build clearance between the contacts since it enables the light arc to expand over a longer length. A longer light arc will increase the resistance, which is desirable when intending to limit the current and decrease the temperature. This will subsequently break the arc and stop the current flow (Sepanski, 2018, pp. 90-93).


*Figure 10:* Dornbirn-suntree Solar-DC-switch-02ASD, Asurnipal, 2021, https://commons.wikimedia.org/wiki/File:Dornbirn-suntree_Solar-DC-switch-02ASD.jpg, CC BY-SA 4.0.

### *Description of dysfunction & operative failure*

The combination of poor quality and workmanship is usually the reason for the operative failure of an isolator switch. The typical findings are that the wiring is unshielded and the switch itself is unprotected from weather phenomena such as rain, hail, snow, wind and heat, that can damage the component. Not uncommonly, there are loose ends and damaged wires that build up a short circuit. This further makes the inverter turn off since the conversion of current cannot be done safely (Libra, 2023).

*Figure 11:* Burnt our isolator on the 300kw roof, h080, 2016, solar panel failure | burnt out isolator on the 300kw roof | h080 | Flickr, CC BY-SA 2.0.

*Figure 12:* Burned isolator switch, 2022, licenced and approved by NÄRF.

## DC/AC inverter

### *Description of function & operative use*

DC from the PV modules must be transmitted into AC to make the electricity practically useful. Therefore, a special component, known as the DC/AC inverter, is applied in the PV system to execute this conversion. The inverter has a filter capacitor across the input, which will make sure that the DC voltage is preserved. Inverters come in different sizes depending on the purpose (Sepanski, 2018, pp. 93-98).

For solar arrays, a string inverter is used to convert all the DC to AC to further distribute the electric power on the facility. The inverter is also responsible for the disconnect of DC/AC conversion in a situation where the grid voltage has collapsed. In such scenario, the inverter should be able to interrupt the current from converting into distributable AC immediately (Franklin, 2018, p. 6).


*Figure 13:* Inverters in a commercial facility, 2023, licenced and approved by Aon.

### *Description of dysfunction & operative failure*

An inverter is one of the most technically advanced components for running a PV system. The inverter consists of several individual components that corresponds to each other. Due to the worldwide demand for commercial PV systems, the production of inverters has been growing so fast that the components occasionally come with a variation of various defects. Some of the most common defects are inadequate dimensioning, interlay connections and poor overall quality of soldered joints. These all pose a “normal” fire risk (Sepanski, 2018, p. 94).

## AC isolator switch

### *Description of function & operative use*

The operative usage of this isolator is to isolate the inverter from the AC distribution box which otherwise will distribute the electricity on the grid. Together with DC isolator switches, according to the international standard, IEC 60364-7-712, it is a requirement that there are disconnect-opportunities on both sides of the inverter. Also in some countries, such as the US, there are special regulations about the requirements for AC isolation switches. In the US this is regulated by the National Electric Code (NEC). Additionally, since they are commercial PV system owners that must transmit their electricity on the national/local grid, a properly dimensioned AC isolator switch may be required by the local utility (Franklin, 2018, p. 6).

### *Description of dysfunction & operative failure*

See “DC isolator switch”.

## Net energy metering

### *Description of function & operative use*

To monitor the effectiveness and stored electricity in a battery a net energy metering component is attached to the system. The metering component will provide guidance and relevant details about the overall operative performance to generate and store electricity. The presentation of generated electricity gives the owner an indication of the potential of transmitting the electricity on a utility grid (Franklin, 2018, p. 7).


*Figure 14:* Net, The Fisches, 2010, https://www.flickr.com/photos/thefisches/4274569171/, CC BY-SA 2.0.

### *Description of dysfunction & operative failure*

Inaccurate measurement of stored battery energy can cause a current overload on the battery. A battery overload can make the metallic melt, which results in an opened electricity circuit. The opened circuit could further provide the right conditions for spark ignitions and subsequently a fire (Maximi Integrated, 2001).

## <u>AC distribution box</u>

### *Description of function & operative use*

In the distribution or junction box, there are circuit breakers for independent branches so that the energy can either be fully distributed to the facility or be connected to the public grid as well (Franklin, 2018, p. 6).


*Figure 15:* Vermont Law School Solar Panel Array-4, 2013, https://commons.wikimedia.org/wiki/File:Vermont_Law_School_Solar_Panel_Array-4.JPG, CC0.

***Description of dysfunction & operative failure***

AC distribution boxes are often reliable, but sometimes they fail due to poor welding. The poor welding of cables induces arcing, which due to small distances between the cables in the box causes a fire (Chang, 2015).

### 4.1.3. Scoping study: Key findings & insights

**Installation errors**

Not uncommonly, roof mounted PV systems are failing due to installation errors. These problems are commonly referred to as lack of standardisation and regulation. Usually, this is visualised through a large spectrum of different equipment, including a variety of cables, connectors, inverters, and arrays. The arrays come in different shape and colour, each with their own composition of components. These components are what can be referred to as "the balance of system (BOS)", meaning that these are essentially the same as the core of the total PV system (Tsoutsos & al., 2020, pp. 9-17).

Except from the technically related issues, there are other obstacles that contribute to the presence of installation errors. There is a large variety of sites and applications that comes with roof mounted PV systems. This embraces installations on various inclinations of the roof, but also arrays that are integrated into the façade, visualised as windows or walls. Since the applications are many, there is a need for a great understanding of building materials for the people both designing and executing the work of these installations. This is especially worth considering if there is a risk for shading. Shading can lead to overheating in the PV array, which consequently can ignite nearby components and initiate a fire (Tsoutsos & al., 2020, pp. 9-17).

Another problem is the variety of different national requirements and responsibilities that comes with PV system installations. First, there must be an administrative approval by the authorities that certifies the installation. This is important in commercial PV system installations since some of the produced electricity most likely must be further connected and conducted to the national grid. Therefore, the workmen who are performing these installations must be able to have open dialogue and be able to deal with the client to safely complete the installation (Tsoutsos & al., 2020, pp. 9-17).

**Poor quality of PV arrays**

As an effect of the increased demand for commercial PV systems, the number of production facilities have been scaled up. Also, since the industry has become more prices driven, manufacturers continuously attract clients with a competitive supply with low costs. Like many mass-produced products, the components are made in China. Naturally, with faster and cheaper production, the quality of the products is affected negatively. In Australia, there has been a study presenting that the PV array itself as one of the major defect components (Zaman & al., 2014, pp. 2-3).

Common faults are glass breakage and issues regarding the back sheet, such as bubbling, delamination and holes. Less common faults are internal corrosion due to water ingress as well as misplaced cables and connectors. These less common faults cause most severance when occurring and are therefore most prioritised. The reason is that they can lead to loss of earthing, which implicates a direct fatality risk (Zaman & al., 2014, pp. 5-7).

**DC arc ignitions**

By the help of an inverter the DC is transformed into AC power to be injected into grid. The DC/AC inverter is a crucial component of the PV system maintain a safe and reliable production of electricity, but there are other components that can malfunction and cause a DC arc ignition. These DC arc ignitions are usually one of most common reasons for resulting in significant property damage.

There have been well-elaborated studies for arcs happening in the presence of AC. The behaviour and other characteristics of an AC arc is well known and is usually visualised as "shoulders", with hardly any zero-current segments in a half cycle. Simultaneously, the characteristics of a DC arc is much more uncertain. For instance, a DC arc do not have zero crossing segments. Instead, it is more persistent. A DC arc is also more sensitive since it depends highly on the inductive behaviour of cables and other surrounding disturbances that with such conditions can trigger the degree of arcs (Artale, 2021, p. 2).

## Hot-spot effect

The hot spot-effect is a result of a potential inducted degradation (PID), where the degradation mechanism slowly reduces the power of the array over time. The degradation mechanism within the array is caused by high voltage between the crystalline silicon-glass surface of the array and the encapsulants. When initiated, the mechanism cannot be stopped or fixed, which subsequently means that the damage that has been done cannot be repaired (Dhimish & M.Tyrell, 2022, pp. 1-3). PID can also be catalysed if there are any cracks in the module that will increase the local heat within the crack. The local heat will consequently develop into a local hot-spot on the module. Researchers are not sure if the PID is directly linked to the event of a hot spot, but it is an aspect that is under magnifying glass. It has been clarified that partial shading or increased resistance of the cells, also known as shunting, influences PID. The common outcome is that it speeds up the degradation of cells in the array (Ibid., pp. 1-3).

The mechanism of a hot-spot effect is usually described as when the current exceeds the reduced short-circuit current, $I_{sc}$. Either one or several cells that are shaded are consequently forced into reverse bias, which usually end up in local overheating. A partially shaded cell, Y will get a lower incident light, $I_{ph}$. Simultaneously, the surrounding cells will generate power in the same string causing a heat build-up. A typical hot-spot scenario is illustrated by the scheme in figure 16 followed by the mathematical formulas for calculating the powered heat, where equation (1) calculates the total powered heat, $P$ and equation (4) calculates the hot-spot effect, $P_{rev}$ (Deng & al., 2017, pp. 79-81).

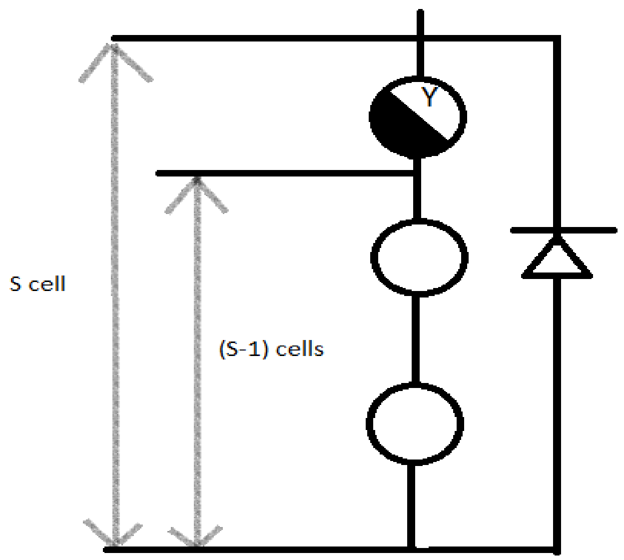


*Figure 16*: Scheme of single cell partial shading in a string.

*Table 2*: Terms and factors for calculation of total heat and the hot-spot effect.

| | |
|---|---|
| $P\ (V)$ | $Total\ heat$ |
| $S$ (-) | $Total\ mumber\ of\ cells$ |
| $P_{illu}\ (V)$ | $Power\ from\ illumination\ (not\ electrically\ generable)$ |
| $P_m\ (V)$ | $Power\ of\ an\ unshaded\ module$ |
| $P_{ph}\ (V)$ | Photogenerated current from the reverse − biased PV cell |
| $P_{rev}\ (V)$ | $Power\ contributing\ to\ the\ hot-spot\ effect$ |
| $E\ (\frac{W}{m^2})$ | $Irradition\ intensity$ |
| $\alpha\ (-)$ | $Cell\ absorption\ coefficient$ |
| $A_{eff}\ (m^2)$ | $Effective\ area$ |
| $I_{sc}\ (A)$ | $Short-circuit\ current$ |
| $I_{rev}\ (A)$ | $Reverse\ leakage\ current$ |
| $V_m$ | $Voltage\ of\ unshaded\ module$ |

$$P = P_{illu} + (S-1) \cdot P_m = P_{illu} + P_{ph} + P_{rev} \qquad (1)$$

$$P_{illu} = E \cdot \alpha \cdot A_{eff} \qquad (2)$$

$$P_{ph} = I_{sc} \cdot (S-1) \cdot V_m \qquad (3)$$

$$P_{rev} = I_{rev} \cdot (S-1) \cdot V_m \qquad (4)$$

(Deng & al., 2017, pp. 79-81).

## **Battery failure**

The produced electricity cannot always be converted to AC and used either for electricity at once or transported on the grid. When the local need is covered and the grid capacity is not able to take care of the electricity, the PV system owner can either choose to turn off the system or make sure that there is a battery where the electricity can be stored until it can be used.

Batteries, also called Energy Storage System (ESS), comes with the benefit that the PV system owner can save the electricity for later use. Although, batteries connected to a PV system can also be a dangerous in terms of fire risk and release of toxic gas. Many batteries that are used for storing electricity from PV systems are lithium ion-batteries. These batteries can be of grave danger if they are damaged in a way that can lead to overheating. The initial overheating and the subsequent fire are direct effects of what is known as thermal runaway. This phenomenon is where the temperature increases dramatically and uncontrollable. When this is started in one or a few cells, it cannot be stopped as it runs fast through the cells like a domino effect (Hoff & Olsson, 2018, p. 1).

The overheating can be caused by several reasons, but most commonly it is another PV system component that ignite, which thereafter lead to a widespread thermal expansion. An ESS should therefore be installed in an enclosure that is clearly separated from the other parts of PV system, such as inverters or isolators (QBE, 2022).

One of the main problems with ESS is that there is no regulation to direct the installation and maintenance of it. Instead, the statements come from local firefighting departments. Since the statements are not legally bound, many of these documents are used for internal purposes only (Hoff & Olsson, 2018, p. 1). According to these departments, the ESS should be stored in rooms that are possible to ventilate, so that the temperature is under control. Additionally, there should be a specific intended fire extinguish system and an emergency switch to turn of the DC.

**Weather-based influence**

On high building roofs, the wind forces are undoubtedly the primary damage element. Other common risks that come with the weather is the exposure of heavy snow load and aggressive hail, but also the risk of direct lightning (Ong & Tohir, 2021).

The exposure of wind is dependent on the site and tilt of the array. A high tilt angle is not uncommonly the reason why the PV arrays are damaged. Even at low wind speeds can cause substantial damage to the modules. One of the most occurring effects due to wind is the vibration phenomenon. Module mounted fasteners that are exposed to vibrations of a regular frequency, such as bolted joints and clamps can easily get loosened even at low wind speeds. This has been declared both through pure visual observation, where the fasteners are either completely or almost off the fixing point, and by using a digital torque wrench tool to accurately measure the loss of tightening (Ong & Tohir, 2021).

*Figure 17:* Bolted joint, 2017, https://pxhere.com/en/photo/1012588, CC0.

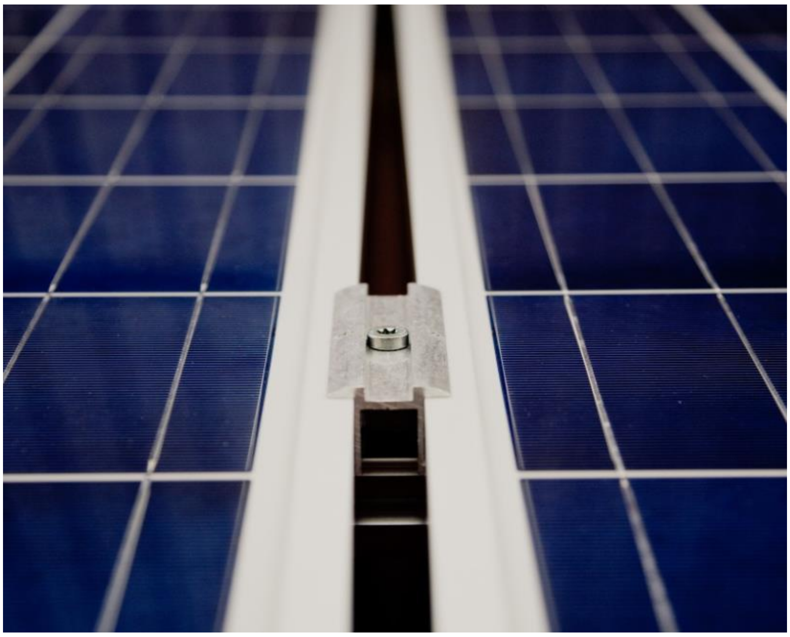

*Figure 18:* Bolted joint, 2017, https://pxhere.com/en/photo/763780, CC0.

#### 4.1.4. Primary data collection: General observations

Interviews were conducted from early in February to late in March 2023. The average person in the respondent group has around 15 years of work experience within property insurances, in risk engineering, underwriting or both. Two respondents were female, four were male.

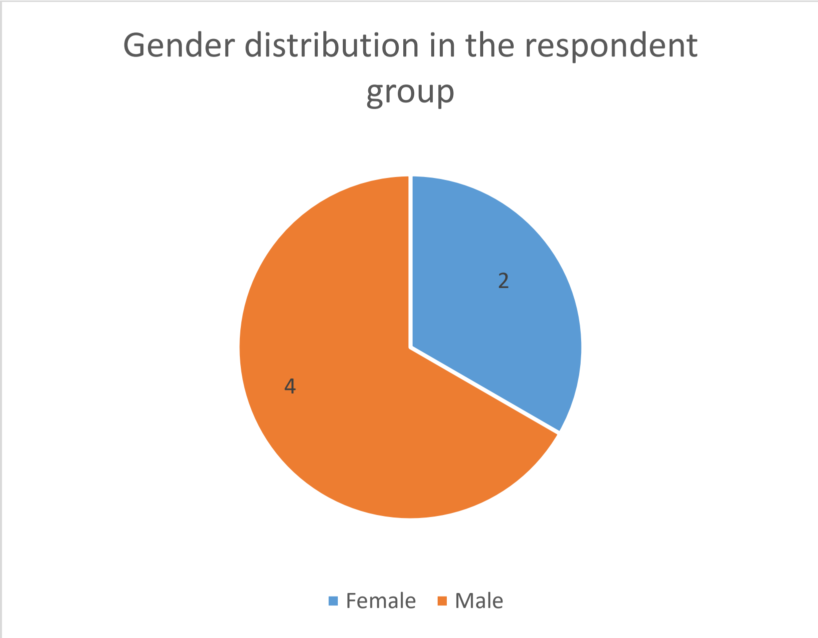


*Figure 19:* Gender distribution in the respondent group.

Several respondents ended up with similar conclusions about the trends and characteristics of commercial roof mounted PV systems. For all respondents, it was clarified that the statistics and collected data was still too narrow and poor to draw any informed conclusions.

Immediate observations from the interviews were that the respondents were all independently unified regarding the questions of common faults, interest for improved hardware and installation regulation, but also what the future challenges are within the insurance industry. Factors such as product quality, correct installation and maintenance were all common denominators that were highlighted during the interviews.

### 4.1.5. Primary data collection: Key findings & insights

Based on the stories and reflections of the respondents, the phenomenon could be described as an uncharted territory. When performing a facility inspection, it is of natural importance to be able to assess the installations. “We need to know, the exposure, a little bit about statistics and how likely it is to fail.” (See Appendix 3, Interview C for statement).

The hardware itself, representing the components in a PV system, was said to be unregulated in several aspects, such as the assemblage, placement, and maintenance. Mismatching components from different manufacturers and unprofessionally made installations are just two examples of what is described as one of today's key issues.

To find the most common faults in commercial roof mounted PV systems, the respondents were asked to score the alternatives that was brought up in the question formula. These alternatives were all examples of common documented faults that was extracted from the literature. The respondents were asked to rank the faults between 1-7, where 1 was the least and 7 was the most common fault. For every fault, each value from each respondent, was thereafter summarised and divided by the number of respondents to get an average value. These values have been converted into points representing the fault frequency.

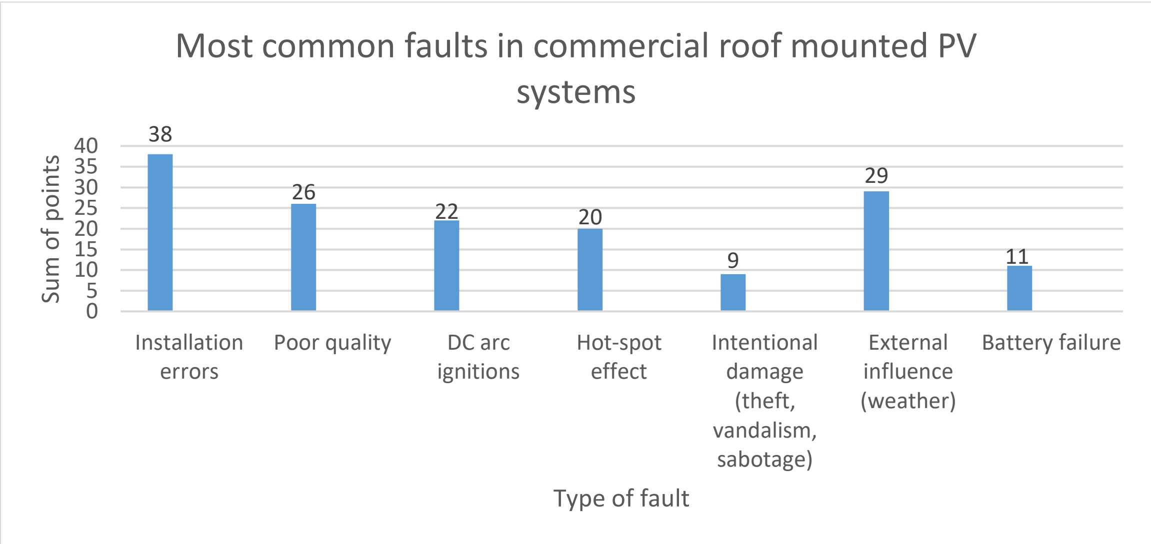


*Figure 20*: Diagram showing the most common faults in commercial roof mounted PV systems.

Even though some faults were more common than others, it was pointed out that every risk in the facility assessment matters. Therefore, all details were said to be relevant and not only single ones when deciding.

> If it is a facility with solar panels on top, then there is an increased risk. A new risk has been added, an ignition source has been added. Therefore, the construction is evaluated in its entirety. (See Appendix 3, Interview A for statement).

**Installation errors**

The most representing issue for all six insurance companies was the aspect of installation errors. It was highlighted by the respondents that installation errors are the most common issue that they see on a frequent level. Installation errors mostly refer to incorrect placement, e.g., inverters, isolator switches and wires. Incorrect attachment of MC4-connectors by using products from two manufacturers is also commonly seen.

Moreover, it was emphasised that there was a strong relationship between inadequate craftmanship and poor product quality. Some of the respondents believed that this was a direct effect due to the rapid development of renewable energy solutions, where the technology runs so fast that the market surveillance and state supervision cannot keep up with the manufacturing pace. According to some of the respondents, the high tempo in product development could be seen as an expected outcome since the interest producing and using green energy in businesses has become more important.

> The trend that we see right now is that many companies that try to produce their own energy one way or another, solar panel is easy because you can buy them, you can put them on roofs, or if you have areas where you can put them.
> (See Appendix 3, Interview D for statement).

**External damage (weather)**

According to the respondents, weather related issues were something that becomes more of a frequent problem, and it was observed both in Sweden and globally.

Even though it was a scattered result on how the respondents put the occurrence of a PV system fault related to weather, it was clear that this was an issue that could be seen globally.

> I think that is the most common thing we see right now. We had some hail losses in the US. And we had some wind losses as well.
> (See Appendix 3, Interview C for statement).

The frequency of damages related to natural hazards were observed more in countries like the United States, where storms, floods, tornados, hurricanes etc. are more occurring. In Sweden, neither the occurrence nor the future expectancy of these hazards was considered as high. This implies that when performing the risk evaluation, the risk for such hazards is much less expected. It is later less disturbing when doing the risk assessment when extracting the basis for an insurance offer. However, since several insurance companies operate worldwide, they are keen on carefully dealing with these hazards when performing the assessment. The idea among insurance companies was rather to encourage these green transition solutions, such as roof mounted PV systems, in geographical areas where the hazardous risks are lower.

> […] I'm not talking about Sweden now, but in some more kept prone areas and I would rather say that it's better not to install it in those areas and focus on areas where you have limited and less exposure to this kind of natural catastrophes.
> (See Appendix 3, Interview C for statement).

However, some respondents were not keen to draw any firm conclusions about the damaged PV systems that seem to be directly weather related.

> So, there is statistics from around the world, yes. […] but it's kind of hard to tell without sufficient amount of data and over a long period of time since the systems, I think this, the general guarantee still is maybe 25 years or something like that.
> (See Appendix 3, Interview D for statement).

**Poor quality**

As previously pointed out, there is a correlation between installation errors and poor quality of components. One common occurrence is that the incoming flow of products is too high and that the training and regulatory equipment for the craftsmen are lacking. Also, since the demand for renewable energy solutions is so high, the high quantity levels are negatively affecting the overall product quality. This mass production also leaves question marks in the industry about the cooperation of components and material efficiency and safety. This was a concern that insurance companies looked seriously upon.

> […] it's more of the end customer not knowing what type of quality materials to buy, mainly going with whatever the installation company recommends and the installation company of course can vary quite a bit in degree of how serious they take the risk of damages over time. So, I would say that's probably the biggest concern.
> (See Appendix 3, Interview D for statement).

Primarily, it is essential components such as the DC inverters that are of great concern due to the mass production. It is also unclear what materials that should be used to manufacture the components and belonging parts.

> […] the biggest concern would be the inverters and making sure that they both from an installation standpoint, but also from a component standpoint are done correctly sort of say. Talking to some of the installers in the area around where I live, it's a big debate on the quality of the cabinets themselves. A lot of people think that they should always be in metal. While some people say that it's the right to have them in plastics and the same goes for components as well.
> (See Appendix 3, Interview D for statement).

**<u>DC arc ignitions</u>**

Poor quality together with poor assemblage of the PV system can cause DC arc ignitions if the conditions are of disadvantage. Based on the response from the interviews, DC arc ignitions happen frequently and were often a main difficulty when insuring commercial roof mounted PV systems. Sharp and loose ends, but also shortened cables are some of the most common observations seen by the insurance industry. In addition, incorrect attachments of connectors are also commonly referred to as the ignite source of an arc.

> […] installation of […] MC4 connectors and doing the shortening of the cables and installing the connectors on site seemed to be an issue […]. So that seems to be a common issue because then you have corrosion due to moisture getting into the contacts. […] it seems to be […] a general problem with degradation in the components used due to sunlight or placement over sharp metal edges that due to the expanding and contracting doing temperature changes you might get chafing or whatever you want to call it and making that risk of having shorts in the system. (See Appendix 3, Interview D for statement).

**<u>Hot-spot effect</u>**

The hot-spot effect was considered as an intermediate fault mechanism that could damage the commercial roof mounted PV system. The respondents were clear that the hot-spot effect was much of a direct consequence due to unfavourable weather influences. Objects that shadow individual spots of the module cells to create a hot-spot, does not appear as an occurrence. Instead, the issue was heavily related to weather influences.

> Hot-spot effect is neither a big concern of ours […]. It is more related to weather and hail damages, like you get a hail damage on the frontside and consequently, you get a hot spot on the backside. (See Appendix 3, Interview A for statement).

Except from weather-based influences, poor quality was underlined as a contributing part for the issue. Sometimes, it was not consequently determined that it was the weather or a shading of solar cells that has caused a hot-spot effect. In such situations, it was decided that it was a manner of quality related source.

> […] unclear if that was a true hotspot or if it was one of the cables or the connecting module below the panel that was part of the fire. But anyway, that came back to poor quality again. (See Appendix 3, Interview D for statement).

**Battery failure**

Based on the interview responses, batteries that are connected to commercial roof mounted PV systems still was an uncharted territory and a rare phenomenon. By most respondents, this was either completely new or at least a much unknown presence.

> About battery failure, we haven't seen anything yet, so therefore it has been marked with a 1. (See Appendix, Interview A for statement).
>
> I haven't seen that many battery failures, so I haven't read about that, but it could be. Due to the fact that the cause of the loss of the incident hasn't been. Let's say it hasn't been analysed in depth. (See Appendix 3, Interview B for statement).

One respondent emphasised the issue with this fault mechanism and that it was something that they need to look further into.

> […] we've seen some claims I would rate that 5. So, sort of common I think we're still in the research and development area. This is an area where I think you can gain a lot in the next coming years, and we see it in situations as well. You know battery fires, both small fires and bigger ones where you have the storage. So, it's something that is on a lot of people's minds at the moment. (See Appendix 3, Interview C for statement).

There was another respondent who believed that the safety assessment for battery storage will become more of great importance in the future, but not related to the PV market.

> I anticipate they are beginning to grow and commend, but not in PV.
> (See Appendix 3, Interview F for statement).

**<u>Intentional damage (theft, vandalism, sabotage)</u>**

In this category, the respondents were united in their standpoints, saying that intentional damage was an uncommon appearance. The interest and motivation to have a commercial facility equipped with roof mounted PV systems as target seems to be outside the radar. The wiring cables and some components may be produced with cooper that can be of criminal interest.

> […] in some countries it's more common to steal the copper or the wires and those kind of things around it. So, it depends a little bit more on the area, but I haven't really experienced a lot of claims from these situations.
> (See Appendix 3, Interview C for statement).

## 4.2. Answering research question 2

For the second research question, *"What challenges and gaps in regulations of PV components, systems and installations are found in the insurance industry and are they described in the scientific literature?"*, the use of the scoping study and the primary data collection have been embraced in conformity with the approach for the first research question.

### 4.2.1. Access to relevant data

Even though the legislations and regulations were deeply embedded and difficult to find, they were seen as clear and comprehensive. In conformity with the interview result in the first research question, there was a broad consent in the respondent group regarding the second research question.

### 4.2.2. Scoping study: General observations

An immediate general observation from the scoping study was that the fast-growing product development in commercial PV systems made it difficult to create regulatory frameworks for how a correctly performed installation and maintenance should be done (Schwab, 2020, p. 1). Another difference was the various approaches for different countries. Some standards were more appropriate and applicable in some parts of the world, while others were less usable. Only in specific parts of the world, such as in large countries in Europe and northern America, there were regulatory frameworks that were clearly defined. By quick thought, a correlation was noticed between the countries being ahead in technology also being well represented by clear regulations.

Even if the general impression was that regulations were hard to find and use, there were many other such tools to use when performing the risk assessment. For example, the International Electrotechnical Commission (IEC), with standards relating to the whole spectrum of PV system safety, representing areas such as component safety, design, installation, and monitoring (United States Agency for International Development, 2023).

### 4.2.3. Scoping study: Key findings & insights

There were two major findings that were extracted from the scoping study. First, it was clarified that there were countries that have come far in developing their own legally binding regulations regarding the spectrum of PV system installations. Secondly, it was found that there was a basis on how PV systems internationally should be regulated.

**Local codes & standards**

When searching for data about the establishment of regulations of PV systems, it was initially difficult to find any clear regulations that were legally binding. Further research showed that the lack of accessible regulations to be retrieved was strongly related to the limitation of national legislation in large countries such as Germany, Australia and the United States. Both in Germany and the United States, there are codes about testing and material quality, but also for installation and monitoring/maintenance (Lawrence Berkely National Laboratory , 2021, p. 1). In the US, codes like ASTM 1830-15 (testing and material quality), DIN 65151 (mounting test of bolt joints), IEC 62548 (wiring requirements), NEC/NFPA (safe installation of electrical wiring and equipment), etc. were used to ensure the safety and maintenance of a roof mounted PV system (Ibid., p. 1).

Compared to the United States, German codes and standards were brought to a broader extent, including further codes on system configurations and specific requirements for individual components within a PV system, such as for modules, inverters, but also storage system where a PV connected batteries are stored. (Sepanski, 2018, pp. 12-20). In Germany, codes like DIN EN 60364 + DIN VDE 0100 (design, connection, and protective measures), DIN EN 61140 (measures for preventing injuries from electric shock), DIN EN IEC 61215 (approval for crystalline modules), DIN IEC 62109 + VDE 0126-14 (mechanical and electrical safety requirements on inverters), etc. are used to ensure the safety of roof mounted PV systems (Ibid., pp. 12-20).

**International Electrotechnical Commission (IEC)**

Some of the above-mentioned codes include the abbreviation IEC, which stands for International Electrotechnical Commission. IEC is a composition of codes and standards that are meant to be used as basis for common understanding and judgement of PV systems, including the risk assessment for insurance companies around the world. The codes and standards are made to cover the risks of full life cycle in a PV system. Therefore, it includes codes for testing, material quality and design, installation, and monitoring. In addition to the care of the insurance industry, these codes and standards are directed with good intentions towards the manufacturers and customers for them to know that a product and service is safe (United States Agency for International Development, 2023).

**Underwriters Laboratories (UL)**

In addition to the IEC codes and standards, there are codes that are meant to be more accessible for underwriters in the insurance industry. These codes are focused on the general balance of a PV system and should be used in the initial phase for the underwriter to judge whether an insurance agreement will be found or not. The idea about these UW codes is to simplify the assessment by directly focusing on parts related to a PV system. In IEC, the codes are more generally written, which can extend the time when performing the risk assessment (United States Agency for International Development, 2023).

### 4.2.4. Primary data collection: General observations

Like the scoping study, it was pointed out that the supply and demand for commercial PV systems was so high that the insurance industry found it hard to keep up with the pace when performing the risk assessment of a facility. The interest in green transition solutions has become of such weight that clients tend to push the boundaries, perhaps unaware of it, when it comes to product and installation safety. The combination of economic interest in reducing the facility costs and the increased awareness of energy sourcing, has directed the focus of the client more towards cost effectiveness and efficiency, while the safety aspect has received less attention. The respondents had a unified opinion that the concept of safety consists of two legs, which were referred to as specific product manuals and general regulations.

### 4.2.5. Primary data collection : Key findings & insights

The common view was that the regulations were poor, both for operative risk assessment and in underwriting. It was clear that some companies had their own guidelines and standard procedures on how a roof mounted PV system installation shall be done, but it usually went back to the individual risk engineer to assess whether it was an acceptable risk or not for the insurance company to take. Some insurance companies used international standards, such as FM Global and NFPA.

**<u>Regulation in risk assessment & underwriting</u>**

Based on the results from the interviews, it was clear that there was currently no regulatory framework that was forced by law to execute the risk assessment regarding roof mounted PV systems, viewed on a global level. When a representative of an insurance company, like a risk engineer, arrive to a commercial facility for an inspection, they do not have any legal demands to assess the installation of a roof mounted PV system. Instead, the risk assessment is done by either following a company self-made guideline or performing an inspection based on the general risk spectrum of the facility. In some companies, international standards such as the National Fire Protection Association (NFPA) can be used to identify the hazards of materials for emergency response, like NFPA 704. In addition, some of the respondents were applying

FM Global standards for property loss prevention. According to the respondents, the clients are obliged to follow these standards to expect any kind of insurance coverage.

> […] We also want that our clients follow the standards framed by FM Global or NFPA. (See Appendix 3, Interview A for statement).

Using another company's regulatory framework was not always an appreciated and applicable approach. Insurance companies are unlike, with various clients and in general different business interests, operating in a variety of markets and geographical areas. Standards like NFPA, that is used in Nordic countries, and FM Global standards, that refers to generally big commercial industries, are therefore not always applicable. Sometimes, they are lacking important details and judged for being too vague. In situations where it is not possible to follow these standards, an individual risk assessment must be performed by a risk engineer.

> […] we are not using legislation that are specific for each country because [...] there might be things that are specific for the individual countries, we have some guidelines and that we should consider that we have risk engineers who are helping me with the risk assessment and they have some more detailed guidelines on how to rate the client […] and they give them different ratings[…].
> (See Appendix 3, Interview C for statement).

In addition, beside using guidelines and standards, some insurance companies used certifications to ensure the product and installation quality immediately and over time. Some of these standards were derived from the United Kingdom and were particularly applied within the renewable energy sector and often have a strong connection to electrical safety. Examples of commonly used guidelines, standards and certifications were the UK Risk Authority guidelines, RC62, LPC standards and MCS certification (Microgeneration Certification Scheme , 2023, p. 10).

> […] The standards that we typically refer to is something called the UK Risk Authority guidelines RC62. It includes recommendations for fire safety with photovoltaic and panel installations, that's one of the guides that we would look at and the other one is a standard called MCS, which is defined as the UK standard, and I think the name is microgeneration certification scheme which is more down to the electrics behind the installation, etcetera, that you have a certified contract etcetera. And then there is also some British or let's say LPC standards around the quality and all they combustibility of the panel, let's say itself, including the frame, and that's one of the standards that we could also refer to. But I think generally. And there is not enough stand that's on the market around these types of installations.
> (See Appendix 3, Interview B for statement).

Although the regulations were lacking necessary information and said to be vague, it was said that there were always rules or established perceptions within the insurance companies on what could be seen as an acceptable risk. While the regulations were not fully developed or well-established, common-sense behaviour along with decision basis from similar contexts were used for the risk assessment. There were several such situations, where the regulation of materials was too vague to answer if something can be managed and where common sense of the decision maker is of greater importance. For example, one established perception was that the use of combustible materials was not optimally suitable in combination with roof mounted PV system. If that was the case, then it was easier for the risk engineer and the underwriter to announce an offer or decline. Another such example was if the installation was said to be performed by certified craftsmen. If there was no certification for the risk engineer to confirm the legitimacy, then it was easier to decide whether it was an offer that the insurance company was willing to take. On the other hand, it was easier to give a green light if there was a legitimate certification. In a normal scenario, the insurance companies present the terms and the rules they have for them to accept a risk to provide an insurance offer. Therefore, it was expected by the insurance companies that the client embraces a progressive approach to make sure that all these insurance related rules are fulfilled before asking for an insurance offer.

> […] tell them to understand what kind of rules we have and then recommend them to use it. [...] you tell your clients that you go ahead and read about what's needed for you, and then for you or for your risk engineers, they want some kind of certificate to see that. [...] I can do my own assessment. But if I get a certificate stating that this installation is proven to be fire safe or something like that, it's easy for me to accept it because then I say OK, I believe I trust this. (See Appendix 3, Interview C for statement).

Based on the answers from the respondents, it was clear that the insurance companies that are operating around the world tend to have rules or recommendations that are usually directly linked to the type of industry.

> […] because our clients are, they normally are spread globally, we are not using legislation that are specific for each country because I know there might be things that are specific for the individual countries […]
> (See Appendix 3, Interview C for statement).

> We have procedure manuals for dealing with various hazards linked to the industry that is relevant to insure. One of these manuals can be applied to insurance of PV systems. Since our company is operating globally these manuals are meant to be suitable for all over the world. Of course, there are national regulations that must be related to.
> (See Appendix 3, Interview E).

In opposition, insurance companies that were mainly operating in Nordic countries tend to have general regulations and rules, but also insurance conditions and terms that were mandatory to follow in whatever industry the client is in. The reason for this occurrence was that there was a difference in market focus. A large insurance company that operates globally naturally does not focus on continents or countries and therefore cannot have regulations for specific countries.

> […] our terms and conditions that say all applicable laws and regulations must be accounted for […] when designing and running the PV systems. On a more information-based level, we also recommend SCR score handbook. […] these are mainly a guideline or a manual for how to do the installation. So, I don't think it's any legal consequence if you don't follow it. And we also have that you should always follow the manufacturers installation and service instructions. So that's part of our terms and conditions as well.
> (See Appendix 3, Interview D for statement).

> The Swedish housing agency building regulation (BBR), high current-regulations, electric installation-regulations, handbook 457 (Swedish Electricity Standards) and recommendations from local fire departments.
> (See Appendix 3, Interview F for statement).

**Wide & holistic approach – The normal case**

It was confirmed by several respondents that it was generally difficult to perform a risk assessment on a commercial facility that includes a roof mounted PV system. When performing the facility inspection, the risk engineer must evaluate not only the separate risks, but look at a broader perspective, visualising the several potential risk scenarios and hazards. This implied to understand how individual risks were likely to tie in with other risks and increase the damage effect and consequently understand how these must be managed to mitigate the overall risk. Therefore, in discussions regarding commercial roof mounted PV systems, it was not only the damage effects on the PV system that matters, but the general damage effect. Concretely, this meant that the representatives, most likely a risk engineer and an underwriter, would look on a wide spectrum of likelihoods and draw conclusions based on that material. Depending on the quality of installations and other risk factors, the insurer chose to offer or decline an insurance offer. This outcome mostly depended on the client, whether the client was willing to improve the parts that were not good enough for arranging an agreement.

> […] we are instead trying to put that into the wider risk assessment of the client and give them some good advice what we think would be better. And then it's a price challenge. If it's too bad, if we realize that they don't know what they're doing, we can decline to insure them. But that's the last resort basically.
> (See Appendix 3, Interview C for statement).

The evaluation of risks in insurance was said to be a question of the facility's number of potential risk factors. Use of wood as a construction material is one risk in terms of combustibility, adding roof mounted PV system is another risk in terms of ignition sources in electrical components. Therefore, it is always an evaluation of the total amount of risks that are relevant to the insurer. Certain risks incorporate certain issues, such as for high rise-buildings with roof mounted PV systems, where it can be difficult for the fire department to reach and fight the fire in a safe way. For the risk engineer and later the underwriter, it is of great relevance to illustrate and compile all risks before making any decision about the insurance coverage.

> If it is a facility with solar panels on top, then there is an increased risk. […] an ignition source has been added. Therefore, the construction is evaluated in its entirety. Sometimes, when we visit these facilities, the solar panels are already installed on plastic roofs etc. For example, if it is a high rise-building, then there is a question about how the fire department is going to be able to reach.
> (See Appendix 3, Interview A for statement).

## Grey zones and special cases: Go/no-go decision

The lack of regulation and the unsureness about the present regulations leaves a gap hole of grey zones and cases where special approaches must be taken. As previously discussed, it is often a manner of combining professionalism and common sense in situations where it is not obvious how to proceed the negotiation between the insurer and the client. According to the respondents, this approach works fine in most cases. An open dialogue and discussion regarding what actions that must be taken in order to get a green light for insurance coverage, was usually not a problem if both parts were on the same page. Still, there were grey zones and situations where it could be difficult to say whether an insurance offer was possible or not. On commercial facilities made with concrete and non-combustible materials on the roof, it was naturally a green light, given that i.e., wires are mounted correctly. On the other hand, if there was a “sandwich layer” of concrete, combustible insulation, and a non-combustible board on top, then it directly become a blurry picture on what appears to be the right approach. Such installations exist and during insurance discussions, it usually becomes a question of tolerance and robustness in case of fire. This is a typical special case where it becomes hard to decide to go or not go for an insurance offer.

> I think we are a little bit in the dark sometimes. One of the areas where it's difficult to come to a firm conclusion, is the roof construction. So again, the roof construction itself is very, very important in the in the evaluation and if you have a concrete roof then it's probably quite straightforward. But let's say you have a steel frame, steel deck roof with a combustible insulation on the top and you wouldn't like the panels to be mounted directly on top of that combustible insulation. But then what about if you install a non-combustible board on top of that combustible insulation? Well then maybe it becomes tolerable and how should that board be and in case you have wall roof penetrations, how close do those penetrations would you be allowed? (See Appendix 3, Interview B for statement).

Insuring a roof mounted PV system on a stand-alone basis was not of a particularly large interest for the insurance companies. The respondents were clear that these installations likely will be re-evaluated and that the attitude might change over time. For now, the installations were yet too unknown in terms of regulatory framework, but also due to that the installations were considered to have a relatively small value that was not of economic interest for larger insurance companies. The present focus among insurers was therefore to look for companies who have the ambition to invest in production facilities with green initiatives.

> […] it's not insured on a stand-alone basis. And that could be the case if you have very large solar panel installations, large energy installations, but it wouldn't be roof mounted facilities. And again, that would be a specific targeted insurance for something that only involves solar panels. And there I think generally in the market there is a limited appetite.
> (See Appendix 3, Interview B).

> We are not interested in insuring PV systems, at least not separately. We insure large scale industrial inventories and factories. We insure industrial facilities with green initiatives, for example sunroof. The solar panel system is usually a part of the insurance of the actual factory. (See Appendix 3, Interview E for statement).

**Battery – a future problem**

The general ascertainment within the respondent group was that batteries that were connected to PV systems were yet not much of a worry. The incident frequency, that directly relates to faults in either connecting parts such as wires or within the battery itself, has not been high so far. This was also a significant reason why the demand for regulatory frameworks was not particularly high.

> Not that's specifically connected to the solar panels. So, we have actually had a couple of recommendations about the battery energy storage systems, more like the container solutions with the lots of battery capacity. […] as for now we don't have anything specifically connected to batteries that are attached to a solar panel array. (See Appendix 3, Interview D for statement).

Although the discussion regarding batteries was yet not a big concern in the insurance industry, there were discussions of significance. In the scope of renewable energy, batteries are becoming hotter on the market. Since batteries are generally something that is much more on people's minds, there is still an awareness and interest about the development in this area within the insurance industry. Respondents were united and clear about the importance to follow the research and development area so that they can provide competitive insurance offers.

> [..] it's a challenge, we're still quite early in the process. So, we had some problems or challenges with this. We have had some claims […] I think we're still in the research and development area. This is an area where I think you can gain a lot in the next coming years […]
> (See Appendix 3, Interview C for statement).

Even though the overall perception of battery fault was considered as a small risk, there were insurance companies that were more speculative about the issues. Generally, the respondents declared that if the battery was stored in a room made of concrete, it was not a much of worry. Some respondents had other reasonings, having a more pragmatic and analytical view on what was important to know when dealing with clients. Factors, such as the size of the battery, placement of the battery (inside or outside), presence of insulation materials in the storage room, possible external physical influences (weather and intentional damage), presence of automatic sprinkler system and fire alarm etc, were emphasised.

> There's something because it's depending on the insulation in the boundary that it keeps different materials from each other, and it's easy that there's just small damage or something that's been damaged in the production process or because some physical violence or impact on it. And that could have resulted in something that is not as tight as it should be, and I think that is the main reason.
> (See Appendix 3, Interview C for statement).

> It depends on how big the scale is, i.e., inside or outside the building. If it's inside the building, then it is fire cell, sprinkler system, fire alarm, but this depends on the scale of this. On that point, we refer to standards, e.g., NFPA.
> (See Appendix 3, Interview A for statement).

## 4.3. Answering research question 3

The idea behind third research question, "*What changes in PV regulations and demands are expected to be seen in a near future?"*, was to use the results from the other two research questions to develop a further reasoning about the future of commercial use of PV.

### 4.3.1. Scoping study: General observations

When the view was pointed towards future regulations of commercial roof mounted PV systems, it was clear that there was a lack of application of already existing regulations in the insurance industry. Some of the demanded future regulations were already existing, but apparently did not seem to be practically applied when performing the risk assessments. Present issues such as lack of CE markings and absence of definitions in various areas, both in production of components and when performing installations, were still uncertainties that were considered to need improvement to create conditions for future insurance solutions.

### 4.3.2. Scoping Study: Key findings & insights

Several relevant key findings were found for future creation and application of regulatory frameworks. Some of the findings were related to improved application of already existing regulations, such as poor practices of operation, monitoring, and maintenance. In addition, some findings were related to the need for new regulations, such as adaptations of regulations that were in line with the development of the Energy Union and the EU electricity market, but also standards to describe the degradation of modules over time and for new technologies, such as building-integrated PV modules (BIPV).

**Need for uniformity when defining PV components, whole systems & installations**

Several factors were emphasised as keys to success for future insurance policies, but one of the most pronounced factors was the present issue regarding clear and comprehensive definitions. Without rigid definitions that can be applied on a worldwide level, the possibilities to make other improvements become either impracticable or substantially more complicated (Dodd &

Espinosa, 2020, p. 14). For future development, a uniformity among the actors should therefore be strived after.

The major issue with present regulations was that there were several different definitions made by various actors, such as IEA, IEC, UL, and PEF (Dodd & Espinosa, 2020, pp. 14-15). For example, asking these actors about the categorisation of PV modules, the outcome would be completely different depending on who you ask, see table 3. Some attributes for a module were more emphasised by some actors, while other disclaim the need for such attributes. Subsequently, due to the lack of consensus between the actors, the creation of worldwide applicable standards becomes impossible. The fundamental problem lies in the variety of claims among these actors. For one actor, energy was most relevant, while for another actor, damage on property and lives were most relevant. There was a consistent theme, where it basically went the same for a system and installations. According to some respondents, representing these actors, some aspects were more relevant to classify a PV system than others. For example, “grid configuration” was considerably higher and more of interest than “mounting structures”. Also, the question if only systems with “specific electricity end-uses” should be included was noticeably questioned (Dodd & Espinosa, 2020, pp. 16-28).

*Table 3*: Recreation of table representing the categorisation of PV module definitions according to IEA, IEC, UL, and PEF (Dodd & Espinosa, 2020, p. 15).

| **Categorisation** | **IEA** | **IEC** | **UL** | **PEF** |
|---|---|---|---|---|
| Size ($m^2$) | | | | x |
| Power output (kWp) | x | x | | |
| Number of cells (e.g 48, 60, 72) | | | | x |
| Structure load bearing form (substrate or superstrate) | | | x | x |
| Framed or unframed | x | | | x |
| Building integration products (e.g., façade panels, sloped and flat roofs, brise soleil, louvres, glass-glass laminates, and roof tiles) | | | | |
| Environmental protection features (e.g., isolation from weathering) | | | x | x |
| Components of a module (e.g., encapsulants, interconnections, junction box) | | | x | x |

**The relevance of understanding the system lifetime, durability & performance degradation**

Beside the importance of clear and comprehensive definitions for PV components, systems and installations, the changes of the technical behaviour over time must be understood. The expansion of the PV market evolves rapidly and new technologies in the industry appear. There was no present regulation that precisely defined the lifetime of a component or a whole PV system (Dodd & Espinosa, 2020, pp. 45-49). Neither did any definitions about the failure modes and degradation of the performance exist. The IEC 61215 (now IEC 61215 series) standard had previously demonstrated the value for failure mechanisms due to mechanical stress, but it had also been stated that it could not be used to assess the risks and predict the performance degradation on a long-term basis. Usually, several parameters along with precise and target-oriented assumptions must be done to make a model of the behaviour of a single component. The model would become even more complicated if the aim was to assess the degradation and failure modes for a whole system (Ibid., pp. 45-49).

To manage that issue, components should be tested in stressful environments that would test the reliability and quality of the components before being distributed on the market. IEC was therefore looking into the possibility of such new standards that would regulate the testing of components. Components such as the inverters and batteries are examples of components that are especially focused on. Exposures in terms of rapid thermal cycling, vibration, high and low temperature levels, and combinations of various effects should be included in the test environment (Dodd & Espinosa, 2020, pp. 45-46).

**Evolution of building codes incorporates changes in future PV codes & standards**

Except from regulations that were purely related to the PV system itself, it was equally important that the regulation for the construction adapted in conformity with the evolution of PV technologies. Codes such as IBC classification is updated every three years and it includes several regulations that are related to PV systems. Matching of fire classification between the roof and the PV system as well as criteria for maximum load of PV equipment were examples of requirements stated by the code. These codes were based on the NEC and UL product safety standards for PV equipment (Argetsinger & Inskeep, 2017, pp. 6-7). The evolution of building codes was said to be crucial for the development of codes in the PV segment since aspects such as building type, roof structure and use of materials were highly relevant for assessing the risks with a PV installation (Ibid., pp. 6-7).

In addition to building codes that were directly related to the construction itself, the development of fire and electrical codes should be improved. Fire codes that naturally take roof mounted PV systems into account could simplify the risk assessment and by so minimise the risk for losing the risk appetite. Future fire codes, such as the codes being developed by IFC and NFPA, should include special considerations for firefighters, so that it becomes easier and safer to access the roof during a fire, but also improve the protection of public health (Argetsinger & Inskeep, 2017, p. 12).

Risk mitigation through electrical codes should also be seen as a major part of the future management of risks related to roof mounted PV systems. Even though, the behaviour of electrical components were expected to be either the same or similar to the current situation, there was room for improvement. Signage and labeling requirements should be legislated and implemented on all facilities with a PV system installation. Critical components, such as inverters, should always be clearly labelled, but also wires attached to certain parts of the roof, i.e. close to modules where firefighters should be able to stand and fight a fire, should be clearly labelled (Argetsinger & Inskeep, 2017, p. 14).

### Greater importance of ecolabelling & recycling criteria

In Germany and the United States there were two present certification programs called the Blue Angel criteria and Cradle to Cradle certification respectively. These programs/certifications were used to describe the attributes from an eco-friendly and a recycling perspective. It was typically the PV modules being evaluated and ranked according to the different criteria, which is visualised by table 4.

*Table 4*: Recreation of table, representing the Crade to Cradle certification (Dodd & Espinosa, 2020, p. 37).

| Attribute | Standard requirements (basic level) |
|---|---|
| 1. Material heatlh | - No banned list chemicals are present above thresholds<br>- Materials defined as biological or technical nutrients<br>- 100 % "characterised" (i.e., all generic materials listed) |
| 2. Material reutilisation | - Defined the appropriate cycle (i.e. technical or biological) for the product |
| 3. Renewable energy and carbon management | - Purchased electricity and direct on-site emissions associated with the final manufacturing stage of the product are quantified |
| 4. Water stewardship | - The manufacturer has not received a significant violation of their discharge permit related to their product within the last two years<br>- Local- and business-specific water-related issues are characterised (e.g., the manufacturer will determine if water scarcity is an issue and/or if sensitive ecosystems are at risk due to direct operations)<br>- A statement of water stewardship intentions describing what action is being taken for mitigating identified problems and concerns is provided |
| 5. Social fairness | - A streamlined self-audit is conducted to assess protection of fundamental human rights<br>- Management procedures aiming to address any identified issues have been provided |

This kind of certifications were expected to increase in the future as they were supposed to be used as a tool for separating the good and sustainable installations from the poor. The idea for the future is that the certifications and ecolabels should be implemented as part of the codes (Dodd & Espinosa, 2020, pp. 33-37).

**Expected new phenomenon: Building-Integrated PV modules (BIPV)**

As the PV spectrum becomes more discovered, there will be more technical solutions in PV. One of the most highlighted installations was the building-integrated modules, also known as BIPV. This kind of installation was expected to take over a large share of the total amount of PV installations, since it will serve double purposes, both as façade or roof construction material and as a source for producing energy (Dodd & Espinosa, 2020, p. 50).

Presently, there was only one series of supporting standards, EN 50583 (2016), that addresses the BIPV modules specifically. As this kind of PV system solutions become more known by the public, the demand was expected to increase. Consequently, there would be a need for improved standards that can be applied on this kind of PV modules.

### 4.3.3. Primary data collection: General observations

The general observation from the interviews was that there was a uniformity in the respondent group regarding the necessity of clear definitions of PV components, system, and installations. This was mainly referring to the definition of a tolerable roof construction and what specifically constitutes a non-combustible PV module. There was a broad general consent that there was a dilemma on what could be considered as acceptable materials concerning a roof mounted PV system installation. Therefore, there was a demand for improved regulation regarding the material issue. Another discussion that was brought out as a critical factor when performing the risk assessment was the lack of easy-detectable signage and indicators for the fire department to use when operating.

There was a variation of opinions regarding the importance of integrating batteries as a part of the general PV system regulations. Some respondents found it as a natural step of the legislative development process while others found it unsuitable due to the component differences between the PV arrays and the batteries.

It was said that an installation of a PV system on the facility roof would not cause a remarkable effect on the premium levels. On that statement, there was a strong consensus among the respondents' view on the future development of premium levels involving an installation of a PV system into the facility. At least in the initial phase, it would not be a dramatic change of premiums, but simultaneously the respondents clarified that this might change over time due to the rapid PV development. Considering the risks that comes with roof mounted PV systems, these are yet considered as an additional risk on the facility. It was said that the facility's whole risk picture was yet to be considered as definite when deciding whether to insure or not.

### 4.3.4. Primary data collection: Key findings & insights

Based on the results of the respondents, it was clear that there were yet a great number of challenges ahead that will complicate the risk assessment and interfere with the possibility of providing an insurance policy. The issue that was mainly circulating among the respondents was aspect of poor definitions. This basically referred to the components within a PV system, but also questions like “what formally defines a system?” and “what is a proper installation?”. There clearly was a strong demand for preciseness, preferably by more national codes and standards. On the other hand, it was highlighted that the experienced delay of definitions was a natural part of the product development and the uncertainties that comes with it.

**<u>Improved clearness of definitions, descriptions & manuals</u>**

In the respondent group it was clear that most of the issues, both in present and within a near future, relate to the problematics of too weak definitions, descriptions, and manuals. There was a broad uncertainty and unawareness about the definitions of components, where the output might be known, but the side effects were unknown. According to the respondents’ answers, the lack of clear definitions made it difficult to assess the size of the risk for a single component. Moreover, the system descriptions are yet considered as limited. The inclusion of elements in a PV system was in several aspects indescribable since it was unclear whether components, cables, wires, batteries etc. should be counted or not. Based on answers from the respondents, the unclearness lied in the large variation of solutions, where some components were fixed right next to the PV arrays, while some other components were fixed on the façade, inside the building etc. This was a typical sight for risk engineers on their site visits and it makes it difficult since it totally becomes a subjective assessment whether the installation in its wholeness be safe or not. Some respondents said that national regulations could be the answer to target this issue. It was said that present codes were either unclear or non-existent. Based on respondent perceptions, the Swedish codes like the BBR, regulated by The Swedish National Board of Housing, Building and Planning, did not cover anything about energy storage in batteries connected to a PV system.

> […] Regulations for safe battery storage is missing and it should already be written in BBR. (See Appendix 3, Interview F for statement)

Other respondents concluded that some critical components were unclear to assess since there were no unambiguous interpretation or clear component definitions, neither any formal manuals that were supported by any legislative basis. The provision of regulative measures of these components were dependent since it had a direct effect on the attitude to offer the client an insurance policy.

> […] the use of optimisers and the location of inverters, which we find very dependent, could be clearer.
> (See Appendix 3, Interview E for statement)

Even though there was a broad consent and a generally positive attitude to merge the PV components into a complete system, there was a dissension among the respondents regarding the inclusion of the battery. The argument was that the PV module and its close-connected components are very alike, while the battery was another type of component that was more than a link component. A battery comprises other risks since it had another function and a different technical behaviour than PV modules, inverters, connectors etc. Instead, it was suggested that the battery should be assessed as a completely own system with its own limitations.

> […] you should always disconnect the battery discussion from the solar panel discussion. I think it's an easy connection to make because it's something that a lot of people are talking about now how to store the energy in combination with the solar panels. But I think the risks involved are very different and it shouldn't be discussed in the same way because the battery has certain types of risks, while the solar panels have a completely different risk situation […]
> (See Appendix 3, Interview D for statement)

**<u>Fire classification & firefighting signage</u>**

Apart from the risks related to property damage, risks related to personal safety was one of the most pronounced arguments in the respondent group. Today´s rapid development of PV components makes it difficult to analyse the behaviour of a potential fire and aftermath of such fires. These aspects were relevant to consider, especially since it directly has an impact on the fire fighters who will fight the fire. Two actions to protect humans from harm were proposed that could be effective both directly and indirectly. Based on the answers from the respondent group, present PV systems were lacking signage or any distinctive indicators that there was a PV system mounted on the roof. For the firefighting team, this becomes an interruption since the lack of information causes a bottleneck effect where relevant construction aspects must be evaluated before the firefighters can start approaching the fire. Contrary, if there were clear signs and a technical map of the PV system, action could be taken sooner.

> […] make it a requirement to have some sort of signage that indicates that there is a solar panel on the roof so that the fire department can identify it easily and quickly when they arrive. […] it needs to be some sort of instruction […]
> (See Appendix 3, Interview D for statement)

On a long-term perspective, as roof mounted PV systems become more established and commonly used, some sort of fire classification should be developed. According to the respondent group, that would protect property even further since the products that were considered as deficient in case of a fire would be rejected by the clients and soon sorted out from the PV market. This would therefore increase the overall safety on property and humans.

> […] What I demand […] is some kind of Swedish standard that is focused on protecting property, for example fire classed solar panels.
> (See Appendix 3, Interview A for statement)

Another discussion that permeated the interviews with the respondents, was the definition of a tolerable roof construction. One of the present main issues and common dealbreakers for the insurance companies was that the roof itself contains combustible materials. Adding a PV system to that kind of roof therefore increases the overall risk dramatically since there are many potential sources of ignition. Dilemmas such as partly covered roofs with combustible materials and boundary layers on top of combustible materials were presently common issues. These uncertainties therefore led to a grey zone, where the risk engineer had to make his own assessment based on subjective perceptions.

> What defines a tolerable roof construction? That's one area that I would like to see more guidance. How should a roof be constructed in order to be considered safe and that needs to cover? And not just how you build a roof from the start, but how to make up for an existing roof that is not really built to the standard as it should have been from the start. Let's say, as I would combustible insulation for example, how to make that safe?
> (See Appendix 3, Interview B for statement)

> […] we should really have a big discussion regarding the combustible installation. […} maybe we can find a way to have a boundary layer of non-combustibility installation or we can find some other way to protect the fire through cables and panels from spreading into the construction.
> (See Appendix 3, Interview D for statement)

**<u>The balance between PV development & insurance policy</u>**

Even though the insurance industry struggles to keep up with the rapid pace of the PV technology, it was pointed out by the respondents that the evolution in technology must come first. Otherwise, there would be a risk that legislation and insurance policy regulations cause an inhibitory effect on the development. Instead, a "learning-by-doing" kind of approach was emphasised by the respondents. By learning from mistakes, focus could be oriented towards the issues that caused the failure. Based on these occurrences, regulatory precepts could be written to eliminate these hazardous causes.

> [...] right now, it's more focused on product developments, process and installation development than finding some legislation that will force people to do it in a certain way because we need to learn, we need to know. We need to learn from our mistakes before we can do that. (See Appendix 3, Interview C for statement)

According to the respondent group, it was still important to acknowledge that in the whole supply chain, from manufacturers, suppliers, customers and so also to insurance companies, there must be an improvement in the general understanding of hazards related to a PV system. With a common sense and respect for all the new-added ignition sources inside or on top of a facility, several risks could likely be re-evaluated to avoid any potential mishap from happening.

> [...] more awareness in the market around the hazards of installing these panels on roofs that are combustible. I think there is a lack of understanding in that respect, and I think, I've seen a lot of examples where panels are about to be installed on roofs that are combustible and no one has really thought about it and then, so I think that there is a lack of awareness on that particular hazard [...]
> (See Appendix 3, Interview B for statement)

There was a well-established philosophy in the insurance industry that in a realistic world, a completely safe facility will never exist. Therefore, regard to this insight, it was more relevant to look at the mitigation possibilities. Based on the answers from the respondent group, there will always be incidents that will involve fires that will cause damage. For the underwriter, it is more relevant to know if there is an action plan to manage these eventualities. The underwriter then knows that there is an awareness of the risks involved, but also that the client is willing to do something about it.

> [...] there will always be incidents and there will always be fires. For us it's more important to know that there is a way to control that or there is a way to reduce the exposure and it's a big difference if you start a fire that will ignite the entire roof or that it's a fire that will stay on top of roof. (See Appendix 3, Interview C for statement)

**<u>Future risk assessment & risk appetite</u>**

When asking the respondents about the risk assessment and appetite for future PV system insurance policies, it was clear that a whole perspective is what matters. Most of the insurance companies being involved in the research were unified on the argument that a facility must be assessed on total risk level, not only by specific installations, like a roof mounted PV system. Not uncommonly, in factory used for large-scale manufacturing and storage, there are many different ignitions sources. In addition, the most expensive machineries, components or finished products are inside the facility. Relatively speaking, a roof mounted PV system is usually of less economic value than these things.

> […] depending on the type of building and the type of building construction, we might do a more severe damage scenario based on the presence of PV. […] our loss scenarios are more connected to the inside of the building where we're all the mostly expensive machineries and the business interruption takes place. […] unless in very, very special circumstances, we're not really taking the solar panel installation into account when we're doing the loss scenarios […]
> (See Appendix 3, Interview D for statement)

Despite the neutral stand on a PV system installation, it was underlined that a visually poor and thoughtless installation will most likely be of less interest for the insurers. If a client does not show any sign of reflection of a poor installation, e.g., that the roof consists of flammable material in combination with a PV system, then the insurance might either be comprised or directly rejected by the underwriter.

> […] we are instead trying to put that into the wider risk assessment of the client and give them some good advice what we think would be better. And then it's a price challenge. If it's too bad, if we realize that they don't know what they're doing, we can decline to insure them. But that's the last resort basically.
> (See Appendix 3, Interview C for statement)

Regarding future risk evaluations of commercial roof mounted PV systems, it was clear that the normal tools for evaluating risks, represented by NLE, MFL, EML/PML etc., were not as applicable towards this kind of installation. The reasoning behind this was simply that a fire that starts on a rooftop will not be reduced by a sprinkler system or any other kind of safety mechanism, since the PV system is directly exposed to the outdoor environment. Consequently, a Normal Loss Expectancy (NLE) might be equivalent to an Estimated Maximum Loss (EML) since it totally is a matter of what other risk factors that were present inside, outside or on the facility.

> If there is plastic material in the roof, then there is no difference between the EML and NLE since there is no sprinkler system. If there is an electrical fault and it spreads to the roof, then there is no difference.
> (See Appendix 3, Interview A for statement)

As described in earlier chapters, there was a great consent to maintain the holistic view when performing the risk assessment, even with the inclusion of a roof mounted PV system. It was emphasized by the respondent group that the entirety of business's risk profile should be considered. Individual deviations should be considered, but in a scenario with a business including several facilities, it should not be a dealbreaker if the risk management otherwise is satisfying. According to the respondents, the risk appetite would be positive if the vast majority of a client's facilities were in line with the expectations of the insurance company. The opposite would be if a client's new installations were permeated with questionable executions, like the combination of combustible roof materials and a PV system. In that case, the approvement for an insurance policy to the client would be much less probable.

> […] if it's only one location out of hundreds then it's something you can live with, because then hopefully there are a lot of positive factors across the entire program that weighs up for that. But if you have a client with only six locations, you know three in Sweden and then and three in in Europe, were half of those locations have PV panels on combustible roofs, then it becomes a critical factor and probably no appetite.
> (See Appendix 3, Interview B for statement)

Specific risks where there is a plan of action for damage mitigation, should not be a reason for a decline by the insurance company, according to the respondents. Even though a PV system incorporates an added risk, it also comes with benefits that should be considered. The same argument goes for a machine or battery. The function itself have benefits that are valuable. Same as a machine should not be close to combustible materials, it is the same for PV systems. It is the combination that might be the cause of damage. The implication of this was that it is either green or red light, depending on the presence of an adverse combination.

> We are, right now, not taking solar panel, the presence of a solar panel system into account when we do the pricing, it's more of a "go no go situation". So, if there is a solar system in combination with combustible insulation for instance, then we say no, no thanks. We're not insuring that.
> (See Appendix 3, Interview D for statement)

Based on procedure and the formalities of the insurance industry, when push comes to shove, the evaluation and pricing is a subjective manner. In the respondent group, it was clear that even with all basis material and knowledge about the risks, it was finally a signature written by the underwriter that critically matters. "[…] it depends on the underwriter and also the size of the business." (See Appendix 3, Interview C for statement) The appetite, professionalism and latitude of this employee is therefore of most significance concerning the premium adjustment.

# 5. Discussion

This chapter contains a discussion based on the answers from the three research questions: "*What is known in the scientific literature and the insurance industry about PV component failures and installation errors over the last 10 years?"; "What challenges and gaps in regulations of PV components, systems and installations are found in the insurance industry and are they described in the scientific literature?*" ; "*What changes in PV regulations and demands are expected to be seen in a near future?"* In this chapter the findings from the scoping study and the primary data collection will be discussed and compared to identify similarities and differences.

## 5.1. Discussing the research findings

The subchapters present the findings from both analysis methods related to each research question. In addition, there will be room for reflection.

### 5.1.1. Findings from the first research question

As previously mentioned in the report, the accessibility to relevant data was mostly satisfying and rewarding. There was also a generally broad consensus in the respondent group regarding the common faults. Since both data collection methods provided similar answers about the common faults in a typical commercial roof mounted PV system, this might indicate, from a speculative perspective, that these issues likely could be globally observed.

There was one clear difference between the results from the two data collection methods, and it was the battery failure phenomenon. In the scientific and grey literature, battery failure was a pronounced issue, while the respondent group stated that was yet not an insurance concern. Much was written about the hazardous events due to malfunctioning batteries and how they might become an issue for future PV systems, but the actual experiences extracted from the insurance companies were not particularly dramatic so far. Being speculative, this might become an issue as the battery technology rapidly proceeds, resulting in weakened quality with product safety deviations.

### 5.1.2. Findings from the second research question

The results from the second research question were interesting in several aspects. For both data collection methods, the lack of world applicable regulations was most pronounced. Based on the scientific and grey literature, problems lied in already established national regulations and the lack of regulations that were legally binding. From the primary data collection, national regulations were mentioned during the interviews, but they were not considered as the major difficulty. Instead, the insurance companies were unified on the point that there are some grey zones where there were no applicable regulations.

The approach difference can possibly be seen as an effect of an insurance company's way of solving problems and maintain profit. From a speculative perspective, the insurance industry might succeed in managing the uncertainty from certain risk factors by focusing on the wider perspective of client's risk profile. Installations that cannot be individually regulated are instead assessed by adding more uncertainty into the client's risk profile. In that way, risk appetite can be maintained, which implies more insurance policies to be provided and therefore more profit for the insurance companies, even though the regulations are not there yet.

### 5.1.3. Findings from the third research question

Based on the results of the two data collection methods, focus was oriented differently in several aspects. The only obvious denominator was the demand for improved clearness regarding definitions, descriptions, and manuals. Apart from that, the interest was much more divided. Being speculative, the academic and operational takes on the future necessities could be seen as very different. Scientists emphasised future action such as improvement of ecolabeling and building codes, while risk engineers/underwriters were more focused on improving the presence of fire signage and finding a balance between PV development and insurance policy. The different approaches on future improvements might lie in keystones such as goals and values. Scientists are more focused on values such as improved quality for a greener production and ecolabeling and recycling criteria are therefore of great interest and consequently their goal. Insurance companies are more focused on profit and retaining clients in their portfolio, which therefore means that solutions, such as fire signage to minimise the direct risks, are of great interest.

### 5.1.4. General findings during the research & future expectations

Based on the perception of the respondents and the international scientific research, the insurance industry had not yet suffered a significant amount of pay outs for claims, where the ignition sources of a fire were related to PV systems. Inside the facilities, inventories and machines were more representative and declared as major causes for property damage. Even though, there were fires that were directly related to ignitions in a PV system, the number of cases was yet small and damaging effects were corresponding.

Looking into the future, based on the forecasts from scientists and the insurance industry, damages that are related to PV system will most likely increase depending on several factors, such as product development and insufficient regulatory framework. Combustible materials and plastics on rooftops will most likely remain an issue for a longer period, but as time goes by there will be new solutions with better understanding and monitoring tools to guarantee maintenance, such as follow ups on degradation and mechanical influence. Nonetheless, as the technology is proceeding along with the improvement of understanding, installations will become better. Meanwhile, as regulations are yet to be formulated, maintenance and monitoring are probably the best approaches to reduce the risk of a fire. For insurance companies, these two aspects should be implemented as standard checks when performing the risk assessment.

### 5.1.5. Research limitations & self-criticism

During the thesis research, obstacles had to be managed and solved to proceed with the research progress. Overall, there were two major obstacles that permeated the thesis research that might have had contributed with scientific uncertainties.

The initial limitation was the low number of scientific articles extracted from a database. Following the search string and using the inclusion criteria meant that hundreds of articles were out selected from reading. Selecting the keywords and inclusion criteria was by that time considered to be a good way of directly focusing on the subject's aim, but simultaneously having a broad question to target a wide range of scientific research. When this issue was realised, a grey literature review was added to compensate for the low number of scientific articles.

With that knowledge and experience, another approach would have been used to manage that issue. Instead of focusing on the research aim in its essence, a broader approach should have been used. This, since the amount of documented research obviously was relatively low. Although, since the number of scientific articles were that low, the thesis research could be seen as a strong contribution for further research through its publication by being accessible to many.

The second limitation of the thesis research was the number of participating representatives from the insurance industry. As previously mentioned in the report, it was difficult to get in contact with these representatives. Not only did the initial contact become an issue, but also the contact maintenance was a strong issue. Even though, contact was made early during the thesis research, it took a long time to arrange and perform all the interviews. The extension of time meant that other possible participants could have been asked to take part in the thesis research. Such requests were not sent. Instead, patiently the author waited and reminded the already invited representatives. The two representatives that did not participate in the thesis research, were also the ones that did not further respond.

With that knowledge and experience, another approach would have been used to manage this issue. Instead of relying on the already established contacts only, more representatives should be asked in the meantime. That way, there would be a back-up plan for the representatives that would have dropped off. Also, with more participation, the results could have been more scientifically credible.

# 6. Conclusion

The aim of the thesis was to answer the three research questions to further describe the rapid expansion of commercial roof mounted PV system installations and how it affects the insurance industry. This was performed by using two different methods. The first method was a scoping study of scientific literature, which revealed information on worldwide scale, both in terms of technical and legislative suppliance. The second method was a primary data collection using interviews, which focused on the present perception of common technical failures in PV, but also the methods being used to assess and evaluate the risks with a commercially used PV system.

To summarise the most relevant findings from the research, based on both study approaches, component failures within a PV system was usually a result of inaccurate and thoughtless placement. In the scientific literature, components such inverters, isolators switches and modules were pronounced as most common failure areas. In the respondent group, loose MC4-connectors were also pronounced as a common failure and cause of fire.

The present legislation was too inaccessible and not particularly useful according to the respondent group. The lack of clear definitions was a problem seen both by the respondents as well as in the literature. The evaluation of risks including a roof mounted PV system was not usually performed differently. If it was a poor installation, the NLE could be equated with the EML. From an underwriting-perspective, it was usually a go/no go-situation, depending on a balanced assessment of the facility risks.

For future legislative improvements, there was a broad demand for codes and standards that could be applicable on a worldwide level to all commercial facilities. Clearness in signage and labelling as well better classification/certification of PV systems and its components were said to be favourable. The future risk appetite was said to neither increase nor decrease. The premium levels were expected to mainly remain at present levels since the total amount of damage related to PV was still not an issue. Loosened risk appetite or increased premium levels were mostly associated with poor installation in combination with combustible materials on the roofs.

In the progress of the thesis research, there were two limitations that might have stretched the scientific credibility. With a considerably low number of scientific articles in the scoping study as well as low respondent frequency for the primary data collection, the quality of the research may have been affected negatively. To take on a similar task for thesis research, some additional strategies could be advantageous to fill the gaps and strengthen the scientific credibility. First, a broader approach on the subject could have been applied, where relevant data from ground mounted PV systems could have been used to roughly illustrate the main issues. That way, common faults seen in both areas of application could strengthen the results of the documented common faults in the thesis research. Notwithstanding, the fact that the scientific literature covered such a low amount of data about insurance of commercial roof mounted PV systems, can be interpreted as there was probably not much knowledge in the subject. That could be seen as an incentive for further research in the field of insurance related to roof mounted PV systems, since there might be more to investigate and analyse.

A proposal for further research within the PV spectrum could be the inclusion of batteries within a PV system. Based on both thesis research methodologies, that was a complexity that was considered to become of greater importance in the future since it was yet unclear whether it should be a part of the PV system or being assessed based on its peculiarity. Therefore, the question about the inclusion of batteries in commercial roof mounted PV system could be a subject for future thesis research.

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# Appendices

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## Appendix 1: Interview formalities

***Aim of the study***

“The main objective of the thesis is to do a systematic literature study as well as a primary data collection  regarding the insurance issue with modern PV systems.

When all interviews are completed, a compilation of the answers will be made to draw conclusions. The further development of these conclusions will lead to a proposal for the tools and other necessities to frame governing documents for future insurance evaluations.”

***Who will listen?***

“The master thesis student (Erik Lindén) will be the only person who will be present during the interview. The master thesis student is also the only person who will have access and can listen to the recorded material. The supervisor from Aon (Karl Borg, Senior Risk Consultant), the supervisor from LTH (Professor Henrik Tehler) as well as the examiner from LTH (Professor Mo Hamza) will only gain access to the recorded material if there are specials reasons. “

***What will happen to the recorded data?***

“The data will be saved and used until the thesis is completed. The thesis work is expected to be finished in early summer 2023. When the thesis is finally submitted and a passing grade is received, the recorded material will be erased permanently. “

“In the thesis, either whole parts or extracts of the recorded data will be written. These extracts will be completely anonymous. For example, if you mention the name of your company while speaking, that name will not be used. Instead, a replacement term could be “Company A”. “

***Where will it be published?***

“After the thesis has been finalised, it will be published by the Faculty of Engineering at LTH.”

## Appendix 2: Interview questions made in Google Forms

***Contact details & working experience***

Your name and professional role:

Ditt svar

Your phone number:

Ditt svar

How long working experience do you have that is related to insurance of PV systems or similar?

- ◯ +10 years
- ◯ 5-10 years
- ◯ 2-5 years
- ◯ 0-2 years
- ◯ Övrigt: ______

## *Characteristics and trends over the last 10 years*

1. Over the last 10 years, what experiences do you and your company have regarding the characteristics and trends of solar panel fires?

Ditt svar

2. Based on your and your company's experiences, what is/are the most common factor(s) that have led to PV system fire accidents? Rang from 1-7, where "1" is least and "7" is most common.

| | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| Installation errors | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Poor quality of PV arrays (material imperfection, fabrication flaws, etc.) | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| DC arc ignition | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Hot-spot effect (partial shading of cell) | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Damage caused intentionally (sabotage, vandalism, etc.) | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| External influence (snow, wind, temperature, etc.) | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Battery failure | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

## *4. Evaluation of risks*

4. How does your company evaluate risks for industrial premises with PV systems?

- ☐ Probable Maximum Loss (PML)/Estimated Maximum Loss (EML)
- ☐ Maximum Foreseeable Loss (MFL)
- ☐ Normal Loss Expectancy (NLE)
- ☐ Neither/Other

## *Follow up on question 4*

If your answer was "Neither/Other"

Describe how your company evaluates risks when insuring PV systems.

Ditt svar

## *5. Regulations and jurisdictions*

5. What regulations and jurisdictions are used within your company when insuring PV systems?

Ditt svar

6. Does your company use any specific regulations/demands for the battery that is connected to the PV system?

- ◯ Yes
- ◯ No

## *Follow up on question 6*

If your answer was "Yes"

Describe the specific regulations for a battery that is connected to the PV system.

Ditt svar

## *5. Regulations and jurisdictions*

7. From your personal and your company's view, are the regulations and jurisdictions clear and easy to comprehend and implement?

- ◯ Yes
- ◯ No

## *Follow up on question 7*

If your answer was "No"

Describe the difficulties, uncertainties etc. about the regulations and jurisdictions that you and your company are using.

Ditt svar

## *6. Future reasoning*

8. In your opinion, what necessary regulations/jurisdictions must be founded to better insure PV systems?

Ditt svar

9. Do you or your company find any other problems that come with the high price on the insurance coverage for PV systems?

- ◯ Yes
- ◯ No

## *Follow up on question 9*

If your answer was "Yes"

Describe the other problem(s) that you or your company find with the high price on the insurance coverage for PV systems.

Ditt svar

## *8. Attitude and willingness to insure*

10. Does your company change attitude and willingness to insure after finding out there is a PV system involved?

- ◯ Yes
- ◯ No

## *Follow up on question 10*

If your answer was "Yes"

Describe how it changes the attitude to insure.

Ditt svar

## *9. Additional input*

11. Is there anything that you want to add or feel is missing?

Ditt svar

## Appendix 3: Interview log & transcript

### Insurance company A

***Recorded and transcribed in accordance with the conditions from the interview formalities:***

Q:

Let's start off with your work experience. How long have you been working with PV systems or similar?

R:

Since we are several persons who have discussed these questions, we have an average work experience of 2-5 years.

Q:

What work experiences do you have?

R:

One of us has been working closely with solar parks, generally large facilities. We have been underwriting the risk for several years. I was recently involved, which was a year ago when I started here as a risk engineer.

Q:

We continue on the characteristics and trends from the last 10 years. What have you been able to see?

R:

I've been discussing this with the claims adjusters and asked for statistics. We haven't received much yet, so there is yet not much to see. Not much have been underwritten. If they are roof mounted, then it's the building itself that is insured. It hasn't been many so far. Our company haven't had that many damage claims, but if you look globally and what we analyse it is installation errors and nature disasters in terms of lightning. Regarding lightning, we see wind as a problem, but wind is more of secondary problem due to a lightning which makes the solar panel unable to turn and switch off. In general, it is installation errors and nature disasters that are the main problems.

Q:

Right. Let's continue on the next question. Based on your experience, what faults would you rank as most and least common?

R:

Again, we are back on that we as company do not receive many damages of this kind, instead we have chosen to look on a general level. We have put a 7 on installation errors. Poor quality of PV arrays, that we cannot find as a problem and therefore that has been marked with a 1. Concerning DC arc ignitions, that we have put a 5 on. Hot-spot effect is neither a big concern of ours, therefore it has been marked with a 2. It is more related to weather and hail damages, like you get a hail damage on the frontside and consequently, you get a hot spot on the backside. About sabotage and vandalism, we haven't seen anything on roof mounted PV systems. We have seen it on solar parks. We don't see any problems otherwise, so therefore it is marked with a 1. About external influences and weather, we have put a 7. On a global level, we have seen clients with this problem. We don't see such a big problem regarding the wind here in Sweden. We have put a high number since we can spot a global trend. About battery failure, we haven't seen anything yet, so therefore it has been marked with a 1.

Q:

A follow up question on damage caused intentionally, theft and theft of copper wires especially. Is that something that you have seen?

R:

No, not on roof mounted PV systems, but we have seen it on solar parks. Usually, it is hard to get up and inside these facilities where there are roof mounted PV systems. There are alarm systems, tag systems all the way and so on. Solar parks, we have seen it though since there are no guards there.

Q:

Let's continue with the next question. This is about your insurance offer. What types of insurances can you provide to a commercial client?

R:

We provide CAR and property, but we also offer liability insurance and cargo on the transport site.

Q:

Which insurance is the most common when it comes to PV systems?

R:

Hard to say since we have both many projects and property clients. I don't I'm able to answer what is most common.

Q:

Let's stop there and move on then. Then it comes to evaluation of risks. How do you perform these evaluations?

R:

We make an overall picture and analysis of each client, but if I'm about to choose then it is EML and NLE that we use. Still, as I said, we include the aspect of the construction, what kind of insulation there is in the roof, how it has been installed, how has the roof been divided into sections with distances etc.

Q:

Could it be that the NLE is equal to the EML?

R:

If there is plastic material in the roof, then there is no difference between the EML and NLE since there is no sprinkler system. If there is an electrical fault and it spreads to the roof, then there is no difference.

Q:

So, it depends on the PV system itself is attached on the roof and that is the normal execution, and subsequently, if something happens, the outcome is the same?

R:

Yes, but it is not always like that. Now, I mentioned the plastic roofs. There is a difference if it is non-combustible insulation. It is usually a case-by-case when performing the assessment.

Q:

Do you see any trends in Sweden or is more common abroad? For example, that combustible materials are more common?

R:

If it is a facility with solar panels on top, then there is an increased risk. A new risk has been added, an ignition source has been added. Therefore, the construction is evaluated in its entirety. If we get to know in time how an installation is supposed to be performed, then we can have a dialogue where we can affect and help to reduce the risk. Sometimes, when we visit these facilities, the solar panels are already installed on plastic roofs etc. For example, if it is a high rise-building, then there is a question about how the fire department is going to be able to reach.

Q:

Next question was actually a follow up question on the previous question, but we have already discussed that, so we move on to regulations and jurisdictions. So, what regulations and jurisdictions are you using within your company when it involves a PV system?

R:

I was a bit unsure about this. What's the difference between regulations and jurisdictions?

Q:

The regulation itself is perhaps something that you have established within the company, that you have your own instructions for this kind of insurances, while jurisdictions is connected to either the national or the international legislation.

R:

In underwriting, there are no regulations or rules. We as risk engineers have made a framework for how we believe it should be installed in order to reduce the risk. Now, I'm speaking of, for example, combustible roofs, distances between solar panels, in other words solar panel sections, where to place the inverter, application of fire classified solar panels etc. We also want that our clients follow the standards framed by FM Global or NFPR. However, they do not regard if there are fire walls in the roof. FM Global only take into account if there is a four-hour wall. So, that's a bit problematic. When it comes to legislation, there are basically none. That is a problem since there are many who installing solar panels on rooftops.

Q:

When it comes to batteries, are there any regulations that you can see there?

R:

It’s a bit like question 5. It depends on how big the scale is, i.e., inside or outside the building. If it’s inside the building, then it is fire cell, sprinkler system, fire alarm, but this depends on the scale of this. On that point, we refer to standards, e.g., NFPA.

Q:

For example, do you use the Swedish Electrical Safety Agency to assess if the installations are done correctly?

R:

Yes, we demand that the client use correct installers.

Q:

So that they are certified and approved? Is that a demand that your company has?

R:

It’s difficult for me to say that we have this demand, but still, we are sharply recommending it.

Q:

Let’s move on to question 7, which is a continuing part of regulations and jurisdictions. From your own and company’s perspective, would you say that these regulations are clear and easy to comprehend and further implement?

R:

The difficulty at the moment is that the standards varies between different countries, German standards contra French standards etc. Sweden does not have one. It would be good if we could get some consensus and uniformity. When it comes to our own regulations, it is at this point difficult to answer since we don’t see any trends on damages so far. They might change when things start to happen. Now, an overall analysis of the building is made, regarding the protection of the building, how do people work there etc. When it comes to legislation, there are none. There is the ISC (International Solar Energy Research Center), but it does not take personal safety into account.

Q:

So, that is something you expect will develop in the future?

R:

Yes, since much is related to personal safety, but not from the property protection-perspective or the risk for a fire to be initiated.

Q:

Ok, then we continue to question 8. According to you, what are the necessary regulations and jurisdictions that are needed to facilitate and improve the insurances of these installations in the future?

R:

As I said before, if you view it from an UW perspective, then it’s not considered to be lacking anything to underwrite. However, we don’t know how it will change in the future if the damage frequency would rise. Then, internal regulations could be added. What I demand, as I was touching previously, is some kind of Swedish standard that is focused on protecting property, for example fire classed solar panels. This because no bad installations shall be done, and it will make sure that electrical faults or similar are prevented. Today, there is a big mix of products. Questions like" how big area is allowed on the roof?", "how far should it be between the panels?", "what does the fire department say?". It's a lot of opinion, but no actual guidance.

Q:

So, clearer guidelines about what applies so that everybody agree. Ok, but then we move on to question 9. Do you and your company see any problems with the price that comes by insuring commercial facilities with PV systems?

R:

In fact, it is not a high price really. If you look globally, we are competitive when it comes to installing PV systems. Since the solar panels are mounted on the roof, they are not individually insured, the whole building is. There are many factors that play in together when assessing the conditions for an insurance. However, if it is plastic in the whole facility and there is a PV system mounted on the roof, then it is question if we want to offer any insurance, but that is another discussion. In Sweden, we cannot see that this kind of insurances are generally more expensive. That is mostly because Sweden doesn't have the magnitude of weather problems that some other countries have. In Sweden, it ground level in electrical safety is generally higher than countries.

Q:

So, it's usually connected to the building itself, that it already has very high property insurance value. So, relatively seen, it's a small cost for the client?

R:

It's hard to tell, but we are at least competitive in this, and the price is not in any way too high to insure PV systems.

Q:

So, you wouldn't say that price is a dealbreaker for the client?

R:

No.

Q:

Ok, but let's move on then. This is about the attitude and willingness to insure. We just discussed this really, but would say that it changes when it concerns a facility with a PV system?

R:

Then I would say yes, but not the willingness to insure, but it becomes increased risk to be considered. You look at the combination of what the construction is made of if wind and hail can affect building and if there is combustible insulation. Such parameters can affect how we look at the total risk. Especially, we want to know these things as quickly as possible so that it is not installed when we arrive without being told. That has happened.

Q:

Yes, and then it happens that you choose to not insure?

R:

Yes, at least it becomes a discussion, e.g., before renewals if agreements about how we are going to handle the risk, i.e., if there is an increase in risk, if the installations are good etc.

Q:

Well, okay. Then we have reached the last question. Do you have anything to add or something that you spontaneously have thought of when you've read the questions?

R:

This is interesting because we have concretised it to installation errors, wind damages, demand of consensus in the business, the execution for correct installation to protect the property perspective. It's nice to see, since we see a huge increase about this, and we receive a lot of questions. Its' mostly real estate companies, where there is a massive increase of PV system installations. So, it has to do with the energy situation in the world.

Q:

Well, then we are done. There are no more questions to answer from this question formula.

R:

Are you happy?

Q:

I'm happy. You're happy too?

R:

Yes.

Q:

Then I'll stop the recording.

**Insurance company B**

***Recorded and transcribed in accordance with the conditions from the interview formalities:***

R:
My background is that I'm a mechanical engineer in my profession. I studied in Stockholm, and I spend a few years in the defence industry for the submarine group. I've been in the insurance industry as a risk engineer in various forms as a manager, as an as a risk engineer in various forms as a manager, as an account engineer, and as a field engineer for about 22 years.

Q:
If we start talking about the characteristics and trends that you've seen in this industry over the last 10 years, what experience do you have regarding the characteristics of PV system failure and damage or fires?

R:
Yeah, I think generally it's kind of a new hazard, I would say let's say 5-6 years ago, it was very, very rare that we came across that. But now we say it's on a very, very regular basis, but I think, and the hustle is such that the installations is still too young to have a broad statistical base upon which we can draw really firm conclusions. If we look at a lot of the other risks that we evaluate. And it goes back from perhaps many decades and where we have a really firm set of data. So, I think we are you know, we are really in in the early stage of understanding these risks and as many of our competitors and then other people and organizations within the industry, it's in the beginning of and when it comes to developing standards, technical guidelines and also pull together the loss statistics et cetera. And personally, it's probably only the last 5-6 years that I've come across all the panels on a much more regular basis. Before that there was the odd occasions here and there.

Q:
OK, so during these 5-6 years, based on your company's experiences, what would you say are the most common factors that have led to PV system fire accidents when you rang them from 1 to 7 where seven is most common in the one is least common?

R:
Like installation errors?

Q:
Yeah.

R:
Yeah, I remember I looked through the options. Shall we go through the options first? And it's obviously not an exact science because we don't have a tremendous broad set of data points, but what about the you list them first and I'll put a scale them in in my order, so to speak?

Q:
Yeah, and then you can rank them in your order. The first one is installation errors.

R:
Installations errors, yeah. And then we have poor quality of PV arrays.

Q:
Yeah. And then we have DC arc ignitions, hotspot effect. Then we have intentional damage, sabotage, theft, weather influence. And last but not least, battery failure.

R:
And seven, is that the most common occurrence or?

Q:
Exactly. You can answer the same rating on two or three if you feel like you can’t place them.

R:
Sure. What's the option after hotspot again between hotspot and weather?

Q:
A hotspot is like when there's something…

R:
Yeah, I mean the and after hotspots, sorry.

Q:
After that it was intentional damage.

R:
Intentional damage, right?

Q:
Yeah, yeah. That could be a vandalism, theft and so as well.

R:
Likelihood or due course due to damage, I would say installation error. Followed by poor quality. There is a very broad, you know, it's very diverse in terms of the quality spectre. They will seem very diverse in terms of the quality spectrum, probably due to a lack of guidance and standards around installations. And you can have, let's regulate the market with supply, a hardware. So, the poor quality is number 2 on the list. The next one is the weather phenomena. Hail is obviously a big challenge. There comes back to the quality of the installation, then hotspots or shading followed by DC arc and sabotage. And the last one is battery failure. From my personal experience, I haven't seen that many battery failures, so I haven't read about that, but it could be. Due to the fact that the cause of the loss of the incident hasn't been. Let's say it hasn't been analysed in depth.

Q:
Yeah. We continue from here. So, if you see the facility has a PV system that is roof mounted, what types of insurance coverage can you offer to the client?

R:
Yeah, there is generally no limitation as such. The apple of my main product is property obviously and then I'm also involved in liability and in construction, but I think with different terms and convictions, we can offer the most.

Q:
Ok, so it's not like divided into construction all risk or erection risk or so? Property insurance?

R:
Yeah, of course the product is, but I wouldn't say it's not such that we can only insure property when it comes to PV panels, but enough liability etcetera or vice versa, but usually we don't insure these installations on a stand-alone basis that are part of something bigger. So, let's say we insure a basis that are part of something bigger. So, let's say we insure a large global corporation, and they decide to install solar panels and that happens to be included in the property values that we insure or it happens to be included in part of the transportation insurance coverage that we provide for certain clients. So, it's not insured on a stand-alone basis. And that could be the case if you have very large solar panel installations, large energy installations, but it wouldn't be roof mounted facilities. And again, that would be a specific targeted insurance for something that only involves solar panels. And there I think generally in the market there is a limited appetite.

Q:
So, when you look at the evaluation of these risks, when you come to facility, how does your company evaluate these risks? Do you use like normal loss expectancy, maximum foreseeable loss, probable maximum loss?

R:
Yeah, generally when it comes to property, we have loss estimates that we work with. One is EML, the estimated maximum loss and the worst case that could happen within certain boundaries. And the other loss expectancy definition that we have is the PML or the probable maximum loss. What's the worst-case scenario given all the protection systems and conditions they have on site. So those are the two loss estimates that we have. And I wouldn't say that the installation of and PV panel system would increase. Either they or neither the EML nor the PML, but it would perhaps increase the frequency of such an occurrence, but it's not that we just because we find a building a factory or a warehouse where there are PV panels. Now that on the roof we wouldn't increase our loss estimates. This is scarily increasing our loss estimates.

Q:
And you wouldn't say that, like the normal loss expectancy, the NLE could be the same as your EML due to that kind of installation.

R:
So in our world, the NLE would be called the PML or the probable maximum loss, but with it resembles a lot of market standard analyse if you like, but not necessarily, but one case where the PML would equal the MFL under these circumstances would be there's a combustible roof and we put a very high weighting on the roof construction when we evaluate these systems and if you have a concrete roof, for example, without any penetrations, et cetera, then we're not so worried about the PV panels on top, less chance of a spread into the building and etcetera. And the main password in those instances would probably be the water damage to the building or the goods below the roof, but we would think we would typically evaluate. Such a situation that the roof would be.  To protect the fire from spreading into the into the building. So, the roof construction is very important in our evaluation.

Q:
Yeah, and if we continue on that path regarding regulations and legislation. What tolls are you using in your company when looking at PV systems?

R:
Good question. There are not that many standards available yet on the market. The standards that we typically refer to is something called the UK Risk Authority guidelines RC62. It includes recommendations for fire safety with photovoltaic and panel installations, that's one of the guides that we would look at and the other one is a standard called MCS, which is defined as the UK standard, and I think the name is microgeneration certification scheme which is more down to the electrics behind the installation, etcetera, that you have a certified contract etcetera. And then there is also some British or let's say LPC standards around the quality and all they combustibility of the panel, let’s say itself, including the frame, and that's one of the standards that we could also refer to. But I think generally. And there is not enough stand that's on the market around these types of installations.

Q:
OK. And a follow up question on that is about the battery itself, are there any specific regulations or codes that you're using for a battery that is connected to a PV system?

R:
No, I would say not in addition to the standards that I just mentioned now.

Q:
OK. And a little bit more about these regulations from your personal and your company's view. Are these clear and easy to comprehend and implement that are existing so far?

R:
Both yes and no. I think that the standards that we refer to, they are or that I just refer to our UK standards and they may not be entirely applicable or it's not possible to translate them into local Swedish standards. For example, in all cases there is a demand in the market to have more of a, let's say, a common framework within the EU or within Sweden. There is a bit of a gap that I would say.

Q:
Yeah, do your risk engineer colleagues today find any like difficulties when evaluating? Do they feel uncertain about how to valuate or judge if it's something that they can insure?

R:
Yeah, I think we are a little bit in the dark sometimes. One of the areas where it's difficult to. To come to a firm conclusion, is the roof construction. So again, the roof construction itself is very, very important in the in the evaluation and if you have a concrete roof then it's probably quite straightforward. But let's say you have a steel frame, steel deck roof with a combustible insulation on the top and you wouldn't like the panels to be mounted directly on top of that combustible insulation. But then what about if you install a non-combustible board on top of that combustible insulation? Well, then maybe it becomes tolerable and how should that board be and in case you have wall roof penetrations, how close do those penetrations would you be allowed? And to put or place the panel, etcetera. So, then with a combustible roof and where you make some kind of preventive measures like a non-combustible board between the insulation and the panels themselves, that’s when you come into the borderline and it's not

crystal-clear case where and what you should recommend and what becomes a safe situation versus a more hazardous situation. So, that's where we are lacking a little bit of guidance that there is also some guidance in that situation. But it's not crystal clear, I would say.

Q:
About the guidance, my next question was about future reasoning. So, there are necessary regulations or legislation, codes or standards that must be found. But what do you see? What must be founded in order to better insure these PV systems?

R:
I think, and if I kind of ranking them in an order. I think, “What defines a tolerable roof construction?” That’s one area that I would like to see more guidance. “How should a roof be constructed in order to be considered safe and that needs to cover?” And not just how you build a roof from the start, but how to make up for an existing roof that is not really built to the standard as it should have been from the start. Let's say, as I would use combustible insulation for example, how to make that safe. Because we won't be able to and prevent installations on all the roofs around the world that contain combustible insulation. So instead, we need to find solutions to those situations, right? So, I think guidance in that area is one. The other one is to define a good or a better definition on what constitutes a non-combustible PV panel and what's a combustible panel. That's another area. And then I think, generally some more common ground around the installation itself, where to place the end of earth, the where to place the manual shut offs, etc. How many shutoffs should you have? And also, some guidance around the first response by the fire department.

Q:
OK so. If we look at another question here that's very much connected to the client. I mean the price itself, the premium, that the client has to pay. Is that something that has been dramatically higher over the last years due to PV systems, and do you find that as a problem when underwriting and then putting a premium?

R:
No, I would say not, I mean the panels themselves are typically just part of a large insurance program where we insure, let's say, a large global corporation, and if they install panels in some of their warehouses or facilities is still a rather benign or limited amount of the total value that we insure.

Q:
And the premium levels?

R:
They’ve been going up in the past couple of years before that there was decline in the in premiums generally, but I think it's more driven by market factors rather than the PV panels themselves. But having said that, if you have, let's say, a client with a limited number of occasions and let's say they have some combustible roof constructions with PV panels on them. That could be the, you know the borderline what makes them, let's say, uninsurable or non-appetite, if you like, but if it's a large client with hundreds and hundreds of locations, then they have PV panels on some of them, that's obviously not enough to have a major impact on the price.

Q:
So, if you feel that it's a combustible roof then you're more likely to decline an insurance offer?

R:
Yes, it's absolutely a big negative factor. But again, if it's only one location out of hundreds then it's something you can live with, because then hopefully there are a lot of positive factors across the entire program that weighs up for that. But if you have a client with only six locations, you know three in Sweden and then and three in in Europe, were half of those locations have PV panels on combustible roofs, then it becomes a critical factor and probably no appetite.

Q:
Do you feel from Swedish profits perspective, is that some kind of remarkable effect where you cannot insure these businesses due to PV systems and has that been affecting your profit?

R:
I would say no, and it has happened that we've declined and offering insurance in some cases where testing the example I gave where we've had a limited number of locations and the overall quality of what we're looking to insure it's not good enough, but generally I would say no, it doesn't. It hasn't had an impact so far. But I think over time in the next 10 years, I think you will, it's likely that we will see losses due to PV panels to a greater extent than what we have seen in the because now we're starting to see so many of them, there's starting to become a good a big number out there and then it's getting more important to differentiate between the good installations and the bad installations, and I think you will see a result of some losses in the future where you can start to see some negative trends around you know some drivers for these losses et cetera.

Q:
So, this question is about attitude and willingness to ensure, but we already almost discussed that completely, I would say. Like it's does your company change attitude and willingness to insure after finding out there is a PV system involved? But that depends, as you say, if there are many factories and so.

R:
Yeah, exactly. And I mean that if the installation, even if it's only one location if the installation is good and a non-combustible roof etcetera then we can accept that. But it's very much up to each individual case.

Q:
So, this is actually the last question and it's about your additional input. If you have something that you that you want to add or feel that is missing. Or something, could be anything really.

R:
Yeah. You know, for me this subject is that the phenomena or the trend, if you like, with solar panels is still compared to a lot of other hazards that we insure and it's still a new and young type of hazard. Even though it's been out there for a couple of years, it's changing so fast and installation or trends in the modules that you saw a couple of years back may not be the same today because it's still under such rapid development. And so, I think we need to have some standards around the hardware going forward. I think that would help us tremendously and I think there will be some losses in the coming 10-15 years, so I'm sure you can start to see some trends and you can start to differentiate between good installations, poor installations and you

will probably also see examples of all the fires with combustible roofs there were worried, limited by PV panels.

Q:
What would you say is the biggest threat in the future about this? Is it the lack of code and standards or is it the fast product development with many different manufacturers? Or is it something else?

R:
I think the biggest threat is if anything is that the there is such a tremendous demand out there, it's growing so fast. So, I think the codes and the standards won't be able to keep up and it means also that when something is growing so fast, there are a lot of new players coming into the market. They're coming into a market that is not as regulated as you would like it to be. So, you will see probably a lot of both installers and manufacturers of the hardware that aren't really up to delivering a good installation or a good piece of hardware. And I think that’s likely to cause losses in this area in the future, so that's another good reason why you need to be very, very careful when you install these installations, how to install them and the brand and the hardware you choose.

Q:
So, you feel that codes more for like how to them on the facilities are more important than actual like the development of each component that can be regulated?

R:
At this time, because it's going too fast. Yeah, I mean I'm, I'm taking a pragmatic view. I think it's unlikely that any codes and guidelines will be able to keep up when the pace of the installation usually codes and regulations, etcetera, they're always behind. And whatever trade or whatever has that you're looking into, but I think, and I would like to say more awareness in the market around the hazards of installing these panels on roofs that are combustible. I think there is a lack of understanding in that respect, and I think, I I've seen a lot of examples where panels are about to be installed on roofs that are combustible and no one has really thought about it and then, so I think that there is a lack of awareness on that particular hazard, I think. Codes or standards could prevent or be like a breaking effect of the product development in the solar panels.

Q:
You mean you're making them safer? And make them better and more efficient and also safer of course.

R:
Yeah, absolutely. I'm very convinced. And I think it would be a shame, wouldn't it, if there would, if we would see a couple of large industry fires or even other fires, potentially with fatalities in the future that were due to poor installations that could have been prevented, and that then suddenly slows or stops? The development of a green energy solution, right? And so, there are some potential roadblocks ahead and that, I think could have a, I mean, they could certainly have a damaging effect on the appetite within communities and within industries to install these in the future. If it turns out that there are a lot of losses associated with these installations and then suddenly or perhaps the public opinion terms towards using this as an energy source, even though that could certainly be the safe solutions.

Q:
I'm very thankful for your participation. I don't have any more questions. So, if you want to add something more, please feel free. Otherwise, I will stop the recording.

R:
Good. Well, I think it was a great conversation. Thanks for having me and good luck with the with the thesis work and hope it was of value.

Q:
Yeah, I'm thankful. I will stop the recording now.

R:
Perfect.

**Insurance company C**

***Recorded and transcribed in accordance with the conditions from the interview formalities:***

Q:
Welcome to this interview.

R:
Thank you.

Q:
This will be an interview for my master thesis work regarding PV systems. The insurance of PV systems. And first, I will read some formalities, the interview formalities.

R:
Yep.

Q:
[Spelling out the interview formalities]

Q:
So, these are the interview formalities. So, let's move on very quickly to the actual questions for this interview. So first, can you tell me a little bit about how much you have been working in this industry?

R:
So, I started in insurance industry in 1995 so it's getting on my 28th year sort of. And the company I worked for right now is an insurance company. I’ve worked here for eight years.

Q:
OK. Have you worked closely to PV systems or similar in particular?

R:
I've mainly had two roles in my career. I've worked as a risk engineer where we assess the risk of the different locations or factories and I've worked as an underwriter where we more look at the entire account and how to access the risk there. And the PV systems comes in as part of that assessment.

Q:
OK. So, if we move on to the characteristics and trends that you have seen over the last 10 years in the in this business. What are the characteristics and trends that you have seen regarding solar panel fires and so?

R:
In general, everything that has to do with renewable energy has increased. So, it's a focus on environment and the solar panel is part of that. The trend that we see right now is that many companies that try to produce their own energy one way or another, solar panel is easy because you can buy them, you can put them on roofs, or if you have areas where you can put them. But normally the factories of our clients have quite substantial buildings where you can install them.

And especially roof mounted solar panels or quite common. We see them. Those kinds of investments are increasing significantly.

Q:
OK. Well, we move on to the next question. So, based on your personal and your company's experiences, if you have to the most common like errors that happen or the things that can happen to a PV system. If you're rank them from 1 to 7, where one is least and seven is most common. How would you put an installation error?

R:
OK, so I need to put in a disclaimer first and I don't have any like statistics with me where we can really look at the claims history and I think to be honest, I think we're too early in this process to actually draw some final conclusions, but I'm happy to answer the questions and to rate it and rank it from based on my common sense approach. If you see what I mean, but not it's not backed up within any statistics. So you said one was the least common and seven is most common. I think it's a little bit more than common than uncommon, so I would just say that it's a 5.

Q:
And regarding quality of PV arrays, material imperfection, fabrication flaws and so, where would you put that?

R:
So, you mean more product?

Q:
Yeah, the product.

R:
Problems with the product I would put it less so maybe 2.

Q:
And then there's another thing called DC arc ignition. Do you know about that one?

R:
Yeah, a little bit. It is indeed something that could occur. And I think it's 4.

Q:
And then we have something called hotspot effect. The shape, maybe like partial shading of a cell or so.

R:
I would say that that is a same as the arcs of 4.

Q:
And then we have, this is maybe a question more to ground mounted PV systems, but also, regarding roof mounted. Do you see any like damage caused intentionally, like sabotage, vandalism, maybe theft or so? What would you rate that?

R:
Well, I would rate it quite low. I would say 1 or 2 and I haven't heard about any of these situations. What I've heard is that in some countries it's more common to steal the copper or the wires and those kind of things around it. So, it depends a little bit more on the area, but I haven't really experienced a lot of claims from these situations.

Q:
OK, and then regarding other external influences like weather related, like snow, wind, temperature, etcetera?

R:
I think that is the most common thing we see right now. We had some hail losses in the US. And we had some wind losses as well. And so, I think that that is quite high. It's around, I would say it's a 6, it's very difficult to put. To install these, the panels in a way that they can resist everything you know. But I'm not talking about Sweden now, but in some more kept prone areas and I would rather say that it's better not to install it in those areas and focus on areas where you have limited and less exposed to this
kind of natural catastrophes.

Q:
Yeah. And the last one here is about battery failure. A battery that's connected to the PV system. Have you seen any problems with that?

R:
Well, I think it's a challenge, we're still quite early in the process. So, we had some problems or challenges with this. We have had some claims we've seen some claims I would rate that 5. So, sort of common I think we're still in the research and development area. This is an area where I think you can gain a lot in the next coming years, and we see it in situations as well. You know battery fires, both small fires and bigger ones where you have the storage. So, it's something that is on a lot of people's minds at the moment.

Q:
What do you see when you see a battery failure? What is the problem with the battery? What causes it?

R:
Well, that's too technical for me, but I would say. There's something because it's depending on the insulation in the boundary that it keeps different materials from each other, and it's easy that there's just small damage or something that's been damaged in the production process or because some physical violence or impact on it. And that could have resulted in something that is not as tight as it should be, and I think that is the main reason. We've seen some while it's more common to see, we heard about phones. When they are being charged. Being overheated. I've heard about laptops, iPads, and those kinds of things as well, but also when it comes to cars and larger batteries too. Normally I would say it's more of a hustle when they're charging, but I think it could happen even without chargers attached to them.

Q:
OK. So, if we move on to your insurance offer. What type or what types of insurance coverage do you offer to an industrial customer when it concerns PV system? Is it CAR, EAR, property insurance or what is it?

R:
Well, I would say that, as you probably will see from other insurance company, we don't exclude this and say that this is not something that we can't insure. However, we try to evaluate it in a good way. So, as an example, if a client asks if they can install solar panels on the roof, the risk engineer would ask the question what the material is of the roof. So, what happens if you have a fire, there will always be incidents and there will always be fires. For us it's more important to know that there is a way to control that or there is a way to reduce the exposure and it's a big difference if you start a fire that will ignite the entire roof or that it's a fire that will stay on top of roof. So, we don't really have any guidelines saying that we can't do it, but we are instead trying to put that into the wider risk assessment of the client and give them some good advice what we think would be better. And then it's a price challenge. If it's too bad, if we realize that they don't know what they're doing, we can decline to insure them. But that's the last resort basically.

Q:
OK, so by that time, you would offer a property insurance as usual?

R:
Yeah, we would, but it's not like we are trying to. And well, selling insurance or offering insurance, it's a different way of selling, so it's more if we can offer some. We can take some risk if we think that the risk is, well, it means that we evaluate the client overall. We say that this is what we think it will cost if we get this amount of premium, we are willing to insure this client. And in some cases we are more pushy and say that we really would like to participate in this program or leave this program or insure this client. But if we take a step back, it's always about us. Looking at the entire risk from different perspectives, comparing the risk itself with the call that we give, we put a price and we'll try to estimate how much this risk should cost and if they can, if the client accepts that's fine, we can make a deal. If not, we can't. And so, it's a matter of coverage and price in the end and not so much about us trying to offer something specific for them. However, there is one special situation which we have the scale, which we have seen that some clients they are interested in finding sort of innovative solutions. A situation, let's say for battery storage where we insure the incident that one out of 200 batteries are failing in an installation. And could we create a product where we replace so that the client pays something to us to take over the risk of replacing a battery in a bigger installation. It's called, well, we call it innovative solutions, but it's not straightforward. Normal traditional insurance product, but it's something where we could make it to the needs of the client. And that has to do with what you need. We need to know. The exposure and little bit about statistics and how likely is it to fail.

Q:
OK, so if we continue on the evaluation aspect.  How does your company evaluate the risks for industrial PV systems? Is this PML or MLE, NLE or is it neither/other?

R:
Well, we call it differently, but we always talk about scenarios. So, what is likely to happen and what is what is an extreme case that could happen? It's not always only about people system, so it's more, I would say a more overarching scenario that we see, so as an example let's say we have a factory and we say that if something happens in this factory, it will burn down. We'll have 100% loss. Then it doesn't matter if it's starting in the production or if it starts at PV system on the roof. We're still consider it's a total loss and we include the cost to replace all the cost or the value of the PV system into the calculation. So that's one way of looking at it. If you take

that, that's more of a quantitative assessment. So, say that this is the worst thing that can happen. This is a likely scenario. And we try to judge how much capacity, how much money we will risk due to this. But that's, as I said, that's the quantitative solution. Then we have to look at the probability of people, probability of something to happen.  So, the frequency of a loss is higher if you have a lot of ignition sources. So, we say that, okay we know that this is the worst case. We know that the worst case that we burn down the factory that´s maybe one out of 2000 times that we have a fire in this factory. Just to give you an example, but how many fires, how many potential fires do we have per year? And in in an office space without any PV panels, maybe we should have one figure, and if we have PV panels installed on roof, we might increase that. So, we might say that this should cost a little bit more because they have more ignition sources. They're more things here that could start a fire. Then if you have an office block without this kind of installation, same thing when it comes to the size of the loss. If everything is in concrete doesn't really matter, but if everything is, if the construction is combustible, it has a different impact.

Q:
But there's no like, let's say it's a combustible roof and you see that there is a PV system installation. Even though you don't use like this PML or stuff, is it likely that you rise the value of the maximum loss due to this effect that they have the combustible roof combined with the PV system? Will that increase the premium directly would you say?

R:
Yes, I would say so. And I would even say that if I get a risk engineering report or risk survey report and it’s stated that it’s a combustible construction and they also have PV panels installed on the roof. Then I would very likely say no thank you to this client and say that this is too risky. We're not willing to offer anything on this for this client normally, but that could be. That's a situation where you have, you know, one building and one set of panels on the roof. And normally we have clients with 200 buildings, so 200 factories or whatever, and if one of those have this kind of installation and this is a combustible construction, that wouldn't be a showstopper. So, then we would weigh that into the greater. The client relationship that we have and see that, OK, they have that. Then we can recommend doing something, maybe we can cover or reduce something. Let's say that we limit this exposure, or we give this kind of exposure a higher deductible and so there are other ways to do it. Maybe we can exclude some things in that we can exclude losses where the fire has been ignited due to the failure of the PV panels, though there are million ways of doing it. It's not always that it's exactly acceptable to the client, but still there are ways to do it, both by increasing the price but also changing the terms and condition for the client.

Q:
But when it comes to a client with let's say 100 factories or so, and 20 of these use PV systems. Is that a neaty insurance and not a facultative insurance that you can offer then?

R:
Yeah. It's always a little bit of grey zone. So, normally we have a broker model or there is a client who needs to buy the insurance so they can come directly to us and ask can you offer something from this, and we can do that in many cases. We can do it on our own or we can do it together with someone else in the current in coinsurance, like we're like 3 carriers of three insurance companies who are sharing the risk. We could also do like some insurance companies do, they say we take 100% of risk, but then they buy faculty reinsurance so they can buy faculty reinsurance for things that they don't like. For example, the buildings with PV panels. And we

don't do that. But we are as a reinsurance company, we have people who are doing that in Munich. So basically, if I'm asked that question, I would say that I'm not allowed to do that because it's not within my mandate. However, there are some people who I know in in Munich who can do that for you or in another country, whatever you want to write in your thesis. So, it's depending little bit if you want to place it. As a client, you need to go to a direct insurance company to find a solution. But as an insurer, you have the option to carve out or reduce the risk by buying factor to reinsurance. However, I think right now the faculty reinsurance for PV panels mounted on the combustible roof is quite expensive. You could probably find it, but it's probably very expensive. So that, yeah, that was a little bit out of topic of this.

Q:
No, that's fine.

R:
But I think it's good to know when interested as part of your learning experience.

Q:
Yeah, of course. But if we if we continue on the next part, which is regulations and jurisdiction. So, what regulations and jurisdictions are used in your company when insuring for this kind of clients?

R:
Well. Not many. We have some like overarching guidelines on things we need to consider, but because our clients are, they normally are spread globally, we are not using legislation that are specific for each country because I know that there might be things that are specific for the individual countries, we have some guidelines and that we should consider that we have risk engineers who are helping me with the risk assessment and they have some more detailed guidelines on how to rate the client to say if they're doing things that are good or if they're doing things that they should or they should improve and they give them different ratings on that. So, there are some guidelines which are very vague from my perspective, but we could, if we need some more detailed guidance, we would ask risk engineer to help us to find details. But it's not as vague compared to other insurance companies where FM global, they have their own standards. There are some carriers, they are using the NFPA codes, so they're always use of the local codes in different countries. If it's a Swedish company they might have the, I think it's called the SBF before it was called the RUS rules, but now it's called the SBF rules. That they can use and refer to for different clients. So, it depends on a little bit, but it's very difficult. But except for NFPA or FM global standards there are some international standards that they can use.

Q:
Codes or?

R:
Yeah, guidelines that are for Europe, but they're not covering everything, especially not from an insurance perspective.

Q:
OK. So, if we continue on the same thing here, but regarding batteries. Is that something that you see? Are there any specific regulations or demands for when it's a battery connected to this system?

R:
No. I don't know. I think there are. I think there are some international codes on how to do that or at least some guidelines. It's not something that we keep and present in that way. However, our risk engineering team, they might use different codes for different standards when they are doing their evaluations.

Q:
OK. Yeah. So, regarding this, legislation and regulations that are present at the moment. Do your risk engineers, do they find these clear and easy to comprehend and implement when working?

R:
When I worked as risk engineer, I think it was some cases you had to go through the details and in those cases, yes, it's a little bit more complicated. It takes a little more time to understand things. Normally you jump into rules that you don't use every day, so you need to understand and get your head around what they actually mean and how to implement them. Because I've never been a like a specialist in high voltage electrical installations. So, say people who work on with those kinds of things everyday they will know exactly how to interpret these rules. So, I think neither for interviewing as a risk engineer or an underwriter it's easy to directly implement something or understand something. However, it's very easy to recommend the client to do it. So, which is a little bit the easy way out. So, you can say that you need to know the rules and what kind of rules to apply and then you tell the client that if I were you, I would get an approval from this standardisation. Because you don't have it yet and you need to make sure that your installation complies with these rules. So that's the easy way to tell them to understand what kind of rules we have and then recommend them to use it. But to get into to understanding the rules and to go into all the details, then you probably need to be a consultant on that specific segment. So basically, you tell your clients that you go ahead and read about what's needed for you, and then for you or for your risk engineers, they want some kind of certificate to see that. Well, we have this now so it's easy for you to underwrite. I can do my own assessment. But if I get a certificate stating that this installation is proven to be fire safe or something like that, it's easy for me to accept it because then I say OK, I believe I trust this. Let’s say an Italian certification and I know the company. I trust that the rules in Italy are sort of the same as in Sweden. So due to that, I would consider it to be acceptable.

Q:
So, if we look to the future. In your opinion, what is necessary?

R:
Legislation must be founded to better ensure PV systems. I think it's not so much about the legislation. I think that is everything that if you take things that comes from the state or regulatory institutions, I think it's mainly focused on life safety. Insurance is something that should cover the losses that no one expected to happen, and it's more about money. It's not so well. Even if we recommend things that would save lives, it's not the main focus, even if it sounds very cynical, I would say, but it's the two different things. So, the state or the country where you live, they have some, some kind of responsibility to make sure that there are safe guidelines when life safety is kept at. Well, the high voltage is not rooted through childcare or schools or something like that, which should be taken off because people can die in case they touched the wires and those kinds of things. Same thing when it comes to batteries. Same thing when it comes to solar panels. They should be installed in a way that we don't lose lives. And

for insurance, insurance kicks in after that and say that, OK, if something happens, we assume that we don't lose any lives, but we might lose some money. And how do we do this in a way so that we don't lose any money? But still, I don't think that strictly legislations are the way forward. I think it's more and learning from things where it didn't work. So, because we're in a in a period right now where there's a lot of new things coming up when it comes to renewable energy, everyone is looking for the Holy Grail where they can solve the world's challenges. When it comes to electricity, power and without creating a lot of CO2s and that we need to have this innovative phase before we can actually see what comes out of it. So it might be that the batteries that are used right now, they're not safe enough. They're not efficient enough. We're always trying and there will be fires. There will be things that happen and that helps us to build even better in the future. So, I think that right now it's more focused on product developments, process and installation development than finding some legislation that will force people to do it in a certain way because we need to learn, we need to know. We need to learn from our mistakes before we can do that. So, I think we're a little bit too early for that. But we still rely on the individual assessment of things and the best practice in different countries and what have worked and what hasn't worked. We have to underwrite and insure based on the moment in the future, you know. The installation types that we can force people to use and that will remove the certain risk that we have. But right now, this is an element where it increases the risk and we try to solve it, price it, and limit it by putting in some terms and condition around it in a way so that we think that the risk is insurable until we know more about it.

Q:
OK. But you haven't heard anything from like colleagues, like risk engineers that, there are many connectors and weird wiring on the roof?

R:
We haven't heard that. Obviously, it's not good to have many connectors on the roof that can cause more fires.

Q:
But since there is not much information about the rules and regulations, is that something that you hear from your colleagues, that they don't know if they can insure this at all due to this problem?

R:
Well, I hear about crap installations I hear about things that. Even for me as being a well not being very knowledgeable in this field when it comes to the actual installation would react on and say that you know, is this really a good idea to do this? So, I've heard about that even if I don't come down to the that count on nitty gritty detail level when I get to submission over when I want to produce a quote. If I have time and I read the reports and I read all the e-mail correspondence and everything, yes, I would react on it and probably tell someone, but it's more something that we discover when we send out the risk engineer or the broker sent out the risk engineer somewhere. So yes, if we had better rules and legislations connected to that, that would definitely improve the type of installations. However, I still think that we are a little too early in the cycle when it comes the boom that we see right now with the installations because it's difficult to if you start making the rules too early and I'm pretty sure that there are some installation rules, but I don't know about them. But if you do strict rules, you might not develop an area in the speed that you need to develop it because you restrict the way of doing things. So, I think that it's probably better to have some kind of functional rules around. These kinds of installations or apply the rules that we have there. There are so many rules for electrical

installations in general, even if they're not considered for this specific type of installation and I think they are good enough. They can probably apply those because there's so much common sense in that and then maybe in a few years time we can start. We can start now, but it's difficult to before we see what works and what that's what doesn't work and what kind of new product comes into the market, it's difficult to get some strict rules in place, I would say.

Q:
So, if it’s a higher price to pay the coverage, if there is a PV system involved, is that something that you feel is a problem?

R:
Yeah, that the clients will say, oh this price is too high. We cannot do this. We cannot pay this premium. Well, that's the two things of doing things, you can, well two types of assessments you can do. You can do technical pricing up to a certain extent, we don't have time to go down and price every little detail over cover. But overall, we can have a discussion about how to come up with a technical pricing and with technical I mean something where we think that the costs, the potential, the expected loss that we see the admin costs that we have is covered. So that we see in the long run, we will have a 5 % profit on this deal. That's one thing, you can be strict and say that if you're below this price level, we can't insure if you're above this. If you can accept the price above this price level, we definitely will insure you, but that is something that changes in the cyclical market that we have. So right now, it's easy to come up with a price and say that this is our technical price, and the client will buy it and they will say yes, we can and that the price is acceptable. 3-4 years ago, the competition was so high. So, if we said that, the broker or the client would just laugh and say that “OK, we have different options here” and in those cases, you need to make a business decision. You say that “OK, we know that the technical pricing is much higher, but we need to continue to grow”. When we take the risk, we grow even if we know that in the long run it's not a profitable, but maybe in one or two years, we can live with it. Even not in a perfect world I would produce everything you know, give everything a technical price and everyone would be happy. We would pay the losses without having a catastrophe result and clients would pay the right price for the for the type of cover that they get.

Q:
But it's not like you lose clients due to this, when you talk about PV systems, no?

R:
We are, as a company, more flexible in our assessments, in our decision making then. A number of other clients, other carriers, main reason for that is that we are. We buy reinsurance but we are not using the standards that the reinsurance company are pushing onto us, some other carriers, they buy more reinsurance and then they reinsurance company asks. My colleagues in another department. They will tell the insurance carrier that you're not, we don't want to see any PV systems in your portfolio and then it will stop writing it. So, we leave it more up to the individual underwriter to decide whilst other companies are more strict on rules. So, to answer your question, no, we are not losing any business.

Q:
OK. And this also answers the next question that I had. It was about the attitude and willingness to insure. But as you said it depends mostly on the underwriter as well, so.

R:
Yeah, it depends on the underwriter and also the size of the business. You know, as we've talked about this, if it's one place and we have 100 locations that are good, you know it's fine. If it's just one site where we have this challenge, we probably say no. So, it's a matter of other things sort of affecting the decision as well.

Q:
OK, so there's only one question left here and it's additional input. So, if you feel that there's something that you want to add or feel that is missing, that's feel free to say.

R:
Not really, but I think that this discussion is quite interesting because on one hand we are in the societies supporting this kind of development. You know, we need to find alternative way of ways of producing electricity, producing heat and at the same time, we see that it's a risky type of installation, or it could be a risky type of installation and it might make us less keen to underwrite it or to write this kind of business. Or if I talk about the general market. So, it's not an easy decision. It's a little bit like, you know, nuclear power. You say it's a cheap, good, very efficient. You get a lot of, very limited CO2 and a lot of production and it must be super good, but then you have a risk that something will happen that you will get radioactivity or radioactive radiation that comes out and kills or create, like, cancer risk for people and there are some good things and some bad things. I think that is the interesting thing that we see in the subject where you that you write your thesis about it's not the straightforward answer then.

Q:
OK. Yeah, but that's the end of this interview.

R:
Cool.

Q:
I want to thank you. I really appreciate that you're on this and I will now stop the recording.

R:
Yeah. Thank you.

**Insurance company D**

***Recorded and transcribed in accordance with the conditions from the interview formalities:***

Q:
I will start by doing the interview formalities.

[Spelling out the interview formalities]

So, these are the interview formalities and now we can begin the interview. So welcome.

R:
Thank you.

Q:
How are you?

R:
I'm good. How are you?

Q:
I'm fine thank you. I think we you can start by talking a little bit by yourself and your experience in this.

R:
Like a short introduction?

Q:
Yeah, very short introduction about your experience and how many years have you worked.

R:
Yeah, well, let's see how many years it's about 10 years now. I started out as a fire safety consultant for a firm in Gothenburg and then a couple years after that, I switched to becoming a risk consultant for Aon and did risk consulting for three and half years. Then I spent two and half years at the fire department in Gothenburg. And then one year and a half ago I switched to risk engineering with my insurance company. So, and few weeks back on the head of the risk engineering department at my current employer.

Q:
OK. So that's a nice background.

R:
Yeah, I have a bit of experience in all the different parts of the building and construction and loss prevention business, you could say.

Q:
Yeah. So, you got the wide perspective of risks.

R:
Yeah, well, there's always more to learn and I'd like to think that I have a good kind of grip on how they discuss the problems and each of their interests in the processes. But with that being said, a lot of things have been changed in the last couple of years. So, it might be a different picture and they call it slow. It's like the risk exposure might be a bit different to nowadays compared to what everybody assumed it would be a couple of years back.

Q:
If we look particularly on the solar panel fires, are there any characteristics or trends that you have seen over the last 10 years?

R:
I think the big discussion was how much the panels degrade over time. Since in Sweden we haven't had any large installations up for more than a couple of years. I think there's maybe one or two big solar parks that have been active for more than 10 years, so it's hard to draw conclusions what our climate might do for the longevity of the panels and how the frost circle might affect them. In terms of both competency but also in degradation of, you know, contexts and components. So, there is statistics from around the world, yes. But it's not always applicable to our kind of climate up here in Sweden. It might be better, it might be worse, but it's kind of hard to tell without sufficient amount of data and over a long period of time since the systems, I think this, the general guarantee still is maybe 25 years or something like that. But there's supposed to be inactive use. So, it’s a long time and a lot can happen in the last couple of years.

Q:
So, I have a list here of different components and other faults as well. Based on your own and your company's experiences, what are the most common factors that have led to a PV system fire accident? And then I have this list here of different kinds of faults.

R:
Yeah, that's the question number two, right?

Q:
Yeah, question number two. How would your rank these?

R.
It's kind of hard to say based on my personal experience, but if you go by what you can find on online or through studies, I would say probably the biggest concern would be the inverters and making sure that they both from, from an installation standpoint, but also from a component standpoint or are done correctly sort of say. Talking to some of the installers in the area around where I live, it's a big debate on the quality of the cabinets themselves. A lot of people think that they should always be in metal. While some people say that it's the right to have them in plastics and the same goes for components as well. If there is, for instance, this emergency breaker present in the inverter, well there always should be, but in case it's remotely operated and things like that and some installers say that, well, that is only made to be used in the extreme emergency, so you shouldn't flip the breaker for maintenance or function control on a regular basis. You should only use it for emergencies, otherwise the material inside will break. So, there's a lot of different takes on the component of quality and the components expected lifetime. But I would say if I only go by my personal experience, I would say that probably the installation. Well, it's usually a fault in the components themselves, but due to installation errors, so for instance. And installation of the quick connect in the MC4 connectors and doing

the shortening of the cables and installing the connectors on site seemed to be an issue compared to factory installation of ready-made lengths of cable with connectors pressed in industrial tools instead of by hand on site. So that seems to be a common issue because then you have corrosion due to moisture getting into the contacts and other sorts of issues like that. But based on what I've read in studies it seems to be that there is a general problem with degradation in the components used due to sunlight or placement over sharp metal edges that due to the expanding and contracting doing temperature changes you might get chafing or whatever you want to call it and making that risk of having shorts in the system and don't use…What do you call it, bogue and arc?

Q:
Light arch, yeah.

R:
And so, you get arcs and stuff like that due to that.
Q:
So, you would say it's part of a manufacturing problem but also installation issue?

R:
I would probably say it's more of the end customer not knowing what type of quality materials to buy, mainly going with whatever the installation company recommends and the installation company of course can vary quite a bit in degree of how serious they take the risk of damages over time. So, I would say that's probably the biggest concern.

Q:
Yeah.

R:
Should I fill out a numbers and stuff in the form or do you want me to do it?

Q:
You can you say it to me now. So, you don't have to fill it in.

R:
Alright, so installation errors. I would probably say a 5.

Q:
Yep.

R:
And then for quality of PV arrays and that we're just talking about the arrays themselves or the panels, right?

Q:
Yeah, it could be. It could be like the cell and then it's the module and the module build up an array, so it's more of the whole panel itself, yeah.

R:
OK. Then I would say probably 7 for the poor-quality PV arrays and DC arc ignition is from my experience mainly due to poor quality but that might be a wrong assumption to make but

I'll probably put that at a 2 or 3. Hotspot, I've only heard about very rarely. I think we had one when I was at the fire department. But I think it was very unclear that was a true hotspot or if it was one of the cables or the connecting module below the panel that was part of the fire. But anyway, that came back to poor quality again. So, about that would probably put at a 2 maybe. And damage caused intentionally, I haven't heard about that. I guess it might be an issue later on when there's bigger solar parks and stuff like that. I have heard about break ins where they stole the solar panels and I don't know if you're putting that into this category, damage caused intentionally?

Q:
I wouldn't say so. Not on the first hand, but yeah, interesting at least.

R:
Yeah, I was really surprised. There was no fence around the property and then he had an array of maybe 200 panels or something like that. And then he came one morning and saw that fifty of them were missing. So, they just cut all the cables and then loaded up in the truck or something. So, it's interesting and it made us kind of re-evaluate how do we want to handle solar panel installations in the future. But we'll get to that. External influence. Would probably put at a 3. Have I picked 3 already?

Q:
You can pick a 3 again if you want to.

R:
Yeah, alright. And most of the issues we had hasn't been through storm and things like that. It’s mostly being the installation company penetrating the outer. That they had alter ceiling so that you get what the damage is inside the building.

Q:
You haven't seen any problems with like hail or something, no?

R:
None yet actually, so I'm a bit surprised. I was actually talking to some of the installation companies that they just put the rails down, mount the solar panels and then they put the concrete stone basically on top of the rails and they say that is enough for the winds that they expect in this area. So seems a bit seems a bit risky to me, but I'm guessing that they have better data to support it to than I have, at least at this time. Battery failure, I haven’t heard anything about not connected to any solar panels at least. So, I'll put that out at 2 in this case.

Q:
OK. But then let's move on or do you want to add something on this list or anything?

R:
No, but if you want to have any discussion around this, I would probably say damage cost intentionally to maybe include also theft.

Q:
Yeah, that is actually included. Yeah, I missed writing that in the form, but that is also included.

R:
Excellent. Because I think that's going to be one of the major contributors to the statistics that we get at least.

Q:
Yeah, and it's also might be a problem with copper being used for the wiring and that could be something that could be stolen.

R:
Yeah of course.

Q:
But otherwise, we could continue on the next question. So, the next question is about your insurance offer.

R:
All right.

Q:
So, what types of insurance coverages can you offer to an industrial customer when it's a PV system involved?

R:
So, I had a question about this. The insurance that you're looking for, is that just for the solar panel installation or is it included as a part of the building?

Q:
As a part of the building.

R:
Alright, then we offer both of the options though.

Q:
Ok, but you don't see like any problems with the PV system when you try to make, let's say, a property insurance?

R:
We do offer it, we have some exception cases where we, well, if we were asked to make an offer, we won't do it in, for example, if we have a large industrial building with the EPS installation, so Styrofoam insulation in the roof and then they are also planning or they already have a solar panel installation on top of that, then we will probably not offer any insurance in that case. But if there is a building with non-combustible installation with the solar panel installation on top of the roof then we don't see any, well we see some issues of course, but not big enough to motivate that it's not interesting at all for us as an insurance company, it's one risk of many. You know buildings of those kind of sizes.

Q:
Yeah. So, if you look at the evaluation of the risks, when you look at like a factor or another facility, what are the industrial premisses when you look at the PV system, is it PML or is it EML? What do you use?

R:
Right now, we only use EML. Same as for all of our other risks, depending on the type of building and the type of building construction, we might do a more severe damage scenario based on the presence of PV. But right now, I think that our loss scenarios are more connected to the inside of the building where we're all the mostly expensive machineries and the business interruption takes place. So right now, we're not, unless in very, very special circumstances, we're not really taking the solar panel installation into account when we're doing the loss scenarios I would say.

Q
But could, let's say a normal loss expectancy, could that be the same as the EML? Just because of the PV systems, because there might be nothing to do about the system when there is a fire or something.

R:
Yeah, maybe, but I don't think so. So, since I'm trying to think of any cases where the fire department's actions might be delayed because of the PV system. So, for instance, if you have a fire in an attic in residential, well, multiple residential building. I think that I wouldn't say it would affect the normal loss expectancy in that big of a degree that you're reaching EML, no.

Q:
OK. If we talk about regulation and legislation, what do you use in your company when there's PV systems involved?

R:
Yeah, we have something in our terms and conditions that say all applicable laws and regulations must be accounted for and taken into account when designing and running the PV systems. So, I guess it would be a cycle as advocates for the gifted. On a more information-based level, we also recommend SCR score handbook. That they follow all the instructions regarding signage and things like that and, but I don't think that's part of the regulation, right, these handbooks are mainly a guideline or a manual for how to do the installation. So, I don't think it's any legal consequence if you don't follow it. And we also have that you should always follow the manufacturers installation and service instructions. So that's part of our terms and conditions as well. So, I would say those.

Q:
OK, so you don't have any specific regulation within the company?

R:
I wouldn't call it regulations. We have some recommendations so I could send them to you if you want to, but those are mainly. Sort of guidelines or recommendations. If one of our customers is thinking about this, the installation of solar panels. So, for instance, as I talked about the combustible installations in the roof, then we very much recommend that you don't do it and a couple of other things like putting all the cables internally through walls and stuff like that, we rather have them visible or, you know, not at all in the building. So, you put the inverters on the outside, for instance. So, I have a couple of recommendations, I'll send them to you, and you can kind of draw your own conclusions on if you want to call them regulations or not. But we have some best practice documents you might say.

Q:
Great! So, can I continue on the next question?

R:
Yeah, sure.

Q:
So, I was thinking about you said you haven't read or seen anything or not much at least from batteries connected to PV systems. So, you don't have any recommendations, regulations or any demands for these batteries that are connected?

R:
Not that’s specifically connected to the solar panels. So, we have actually had a couple of recommendations about the battery energy storage systems, more like the container solutions with the lots of battery capacity. So that's the thing that we're looking at and it might be expanded to also include the smaller battery boxes that might fit in the basement or having like the smaller size batteries that you can fit inside the building and things like that. As for now we don't have anything specifically connected to batteries that are attached to a solar panel array.

Q:
OK, and a final question about the just legislation and regulation part here. Do you and your colleagues, the risk engineers, do they find these clear and easy to comprehend when implementing them?

R:
Yeah. How should I put this...? The regulation regarding electrical safety is for a nonprofessional kind of hard to interpret, I haven't heard that they're really insufficient for us, the installation process goes, but there is really a lot bigger question regarding the installation or the system when it's installed and in use. That leaves a lot to be desired, so there is very little about regular maintenance, for instance, and there's nothing about how you should take care of your system. There's nothing about how you should inform the fire department about your system. So, I think the installation part is probably fine. I'm sure the management of the system and what information goes out to all the stakeholders when you put it in a building, that's very lacking right now. I think they kind of intentionally left it to the market or whatever they want to call it, decide what's the best practice because it's hard to find the regulation that fits all types of situations, everything from a single house to the huge ground-based systems that we have. So, it might be hard to find a golden middle that everyone can fulfil but still have a good amount of protection from. You know the type of damages that we might see.

Q:
Yeah. So, but what if we look further in the future. Regarding the regulations, in your opinion, what must be founded to better insure the facilities with these PV systems?

R:
I would say the first one just on my wish list, with my background, I would make it a requirement to
have some sort of signage that indicates that there is a solar panel on the roof so that the fire department can identify it easily and quickly when they arrive. And I think that there needs to be some sort of instruction or guidelines for how to design the system in terms of distance

between fire separations between different buildings even though they're built together and access to the roof and so how to
walk between the panels and distance between the panels and the system to, for instance, smoke hatches and smoke ventilation and other sort of openings in the door. If you could get those things in place, you would solve a lot of problems and then specific like work methodology for the fire department. I think that's better left to them to work out something that works for them because as we talked about
things kind of moves really quickly in the industry and a safe the system that might be the gold standard today might not be the best option tomorrow. So, it's a bit hard to make strict regulations in terms of what safety systems need to be in place before. There is a really good way to ensure that it's the best system over time as well.

Q:
OK. So, the next question here is about the premium or the price for the client. Sometimes the price can be increased due to the coverage of a PV system involved. Do your clients find this price high? Is it a problem for you as an insurance company?

R:
I cannot speak for all the insurance companies, but we are, right now, not taking solar panel, the presence of a solar panel system into account when we do the pricing, it's more of a "go no go situation". So, if there is a solar system in combination with combustible insulation for instance, then we say no, no thanks. We're not insuring that.

Q:
So, it's a small effect on the pricing?

R:
It's more of a "go, no go situation". Like, we're not going to insure that at all in the future. We might do a bit of a premium adjustment based on the presence of solar panels. But right now, there's nothing that we do and it should be noted as well that we don't, to my knowledge at least, we don't insure free standing solar panel systems. So, the ground-based ones I think with the set node to the ones that we've been asked to make offers on because the risk of theft and damages is a bit too high at the moment.

Q:
Alright so. If we look to, yeah, you talked about this. This is about the attitude and willingness to insure. So, you basically said that the attitude and willingness to insure doesn't change right?

R:
Not currently, no. So, it's not the PV system itself, it's more the PV system in combination with other risk factors that might make it unattractive for us as an insurance company.

Q:
Alright so. This is the last question that we come to and it's about your additional input. If you have something that you feel is missing or you want to add, feel free to say it.

R:
Yeah. I personally think that you should always disconnect the battery discussion from the solar panel discussion. I think it's an easy connection to make because it's something that a lot of people are talking about now how to store the energy in combination with the solar panels. But

I think the risks involved are very different and it shouldn't be discussed in the same way because the battery has certain types of risks, while the solar panels have a completely different risk situation, but I know why everyone does it. I did it myself when I was in the fire department and everybody kind of asked about them in the same conversations. But I think it's a good idea to separate the two when doing studies and when doing regulations and when talking about the methods used by the fire department because it's two very different systems. I'm trying to find a good example, but you know in a regular building if you have an incoming gas line and it's connected to the stove. That's one risk, but if you have bad electrical wiring, all old electrical wiring, that's another risk. So, it's not really comparable. And I think because you want to have an answer for the battery situation, sometimes the conversation gets stopped regarding the solar panel installation because we can't figure out the battery question, but instead just leave that completely off the table, talk about the solar panels and talk about the solar systems and try to figure out how to best manage those risks and then we can talk about the batteries and another conversation. Yeah. So that's uh, that's my opinion at least.

Q:
Yeah. And if you look on PV systems in the future, let's say, 10 years from now, well, where are we then?

R:
I had a talk about this actually. I think we're going to see more often the integrated solar panels. So instead of having a roof at all, it's just the solar panels. So, it's going to be a lot more internal wiring on the inside of the building, and I think that it's just a matter of time before there's an EU regulation to have it on any large industrial building, at least to be partly covered by solar panel installations. And with that in mind, I think we should really have a big discussion regarding the combustible installation. Yeah, that's a lot of people still put in the roofs and how if they still want to have it, maybe we can find a way to have a boundary layer of non-combustibility installation or we can find some other way to protect the fire through cables and panels from spreading into the construction. Because right now, there is no, I mean a sprinkler system only works when the fire is inside the building. It doesn't work when it's inside the construction. So, if that happens, then we're basically screwed. So yeah, I think there needs to be discussion about what types of combinations of building materials you can have with the solar panels. And I think, and I hope that we get there soon, either through every insurance company setting their foot down and telling them, telling our customers that no, you can't have it this way, or if there's a building regulation or whatever. But I think we need to come to a conclusion there that it's either combustible insulation in the roof or it's all panels, not both.

Q:
We'll see. It's a big discussion, yeah.

R:
Yeah, I know. And it's a big, big change from the situation that we have right now.

Q:
I think we're done with this interview now. So, I want to thank you for participating. Then I will stop the recording and thank you.

R:
Alright, thank you.

**Insurance company E**

***Telephone interview that has been noted and transcribed in accordance with the conditions from the interview formalities:***

***Role and experience:***

Mr. X works as an account consultant, and he has 23 years of experience in insurance and reinsurance. In his role, he has a responsibility to steer field engineers (risk engineers) within the company and to overall coordinate the work.

## 1. *Experience over the last 10 years*

"Based on my own experience, I would say that industrial usage of PV systems is more prevalent. Particularly, this have been seen over the last 18 months."

"I would probably say that, based on what we have seen during the last 18 months, there have been occurring problems with inverters and the roof mounted PV system itself."

## 2. *Most common factors*

1) Intentional damage + Battery
2) External damage (weather)
3) Hot spot effect
4) DC arc ignition
5) …
6) …
7) Installation errors

## 3. *Insurance coverage*

"We are not interested in insuring PV systems, at least not separately. We insure large scale industrial inventories and factories. We insure industrial facilities with green initiatives, for example sunroof. The solar panel system is usually a part of the insurance of the actual factory."

"We have property insurance of a factory. We do not offer a CAR/EAR insurance. Instead, we only insure complete projects."

## 4. *Evaluation of risks*

"We use all of them. MFL, PML and NLE. There is usually a need to look at all variants to get the full picture."

"NLE can sometimes be as high as MFL because of combustible materials in the roof where the solar panels are located. A fire in the roof can therefore be dependent for further fire in the whole construction.  Since the sprinkler system is located on the inside, it cannot make any difference."

“The real problem is to decide the NLE, since the panels are located on combustible roofs.”

### *5. Regulations and jurisdictions*

“We have procedure manuals for dealing with various hazards linked to the industry that is relevant to insure. One of these manuals can be applied to insurance of PV systems. Since our company is operating globally these manuals are meant to be suitable for all over the world. Of course, there are national regulations that must be related to. “

### *6. Regulations for batteries*

“I have not seen any batteries. We have some regulations for battery storage, but that is for turbine energy. Not any appliance in PV systems.”

“I anticipate they are beginning to grow and commend, but not in PV.”

### *7. Regulations and jurisdictions: clearness & comprehensiveness*

“It’s okay. Some are a bit oriented towards electrical engineering. In general, I’m happy about it. It’s quite old though, about 5-6 years old.”

“The legislation is changing very quickly and makes the environment even harder. Again, what we want to know in the first place is: what is the roof construction material?”

### *8. Necessary regulations*

“Main thing to be regulated is whether the control of the outcoming voltage is best regulated on the roof itself or on the ground. Also, the use of optimisers and the location of inverters, which we find very dependent, could be clearer.”

“The second thing is that a lot of combustible materials, particularly in the US, are being used in the roof construction. Especially the insulation materials are of great concern since they are very combustible. It is therefore important to ask how these facilities can be improved to install PV systems.“

### *9. Problems with the premium price*

“No, not at all. The building value is usually already very high, so in relation to the building it’s a small cost. The value of insurance for a PV system is non-significant. Sometimes it might be found that with a combustible roof, the company might refuse to insure the facility, or it will be comprised”.

“We always view the PV system in its risk of hazardousness. If it’s a combustible roof, with a large building value and big amounts of inventories, then the price is higher due to higher risk. Without combustible roof, it will be a nominal effect on the property insurance of the facility. Concretely, it’s all about the roof.”

### *10. Attitude & willingness to insure*

"Chief executives say that with new technology, with regards to the environment, we cannot afford to ignore it. We need to know everything about the PV system (installation, running period, etc.). Assessment is needed to insure. The engineers that are operating in the field usually come with recommendations about the situation when they are doing these assessments. In other words, we need to include these new technologies when doing assessments for future facility insurances."

### *11. Additional thoughts*

"About the procedure manual; when it was first written, underwriters said that the PV system must be classified with the scale A, B, C and so forth. When looking for these classifications when operating, almost none could be found. Only a C mark was found."

"I believe there is a need for uniformity of legislation and standards that everyone within the insurance industry is happy with."

**Insurance company F**

***No interview. Answers are extracted from digital question form.***

***1. Experience over the last 10 years***

"5-10 years"

***2. Most common factors***

1) …
2) …
3) DC arc ignition
4) Poor quality of PV arrays
5) …
6) …
7) Installation errors

***3. Insurance coverage***

"CAR/EAR and Property Insurance. "

***4. Evaluation of risks***

"Neither. "

*Follow up on question 4:*

"The individual case is assessed based on the risk analysis made by the broker. The location of the PV arrays is important. If the PV arrays are located on a production facility with already high values (inventories and interruption) it becomes an increased risk. The usage of construction materials is of value, since a combustible construction implies an increased risk. In every case, we demand that the PV arrays are installed correctly. "

***5. Regulations and jurisdictions***

"The Swedish housing agency building regulation (BBR), high current-regulations, electric installation-regulations, handbook 457 (Swedish Electricity Standards) and recommendations from local fire departments."

***6. Regulations for batteries***

"No specific regulations for batteries being connected to a PV system."

### *7. Regulations and jurisdictions: clearness & comprehensiveness*

"The regulations and jurisdictions are clear and easy to comprehend and implement."

### **8.** *Necessary regulations*

"We consider the available regulations and legislations as clear, but other regulations for control and maintenance of the installations should be found. Special training/certification for installers would be good. Regulations for safe battery storage is missing and it should already be written in BBR. How should fire protection be secured for battery storages?"

### **9.** *Problems with the premium price*

"Not a problem."

### **10.** *Attitude & willingness to insure*

No response.

### **11.** *Additional thoughts*

No response.

## Appendix 4: Email correspondence

Except from the contacts with representatives of various insurance companies, contact has been made with representatives of various fire departments in Sweden.

### Following questions were sent out to various fire departments and agencies in Sweden:

1. Which/what components is/are most commonly the reason for the occurrence of a fire?
2. Does the fire usually spread further to the roof construction? What construction materials do you see in the roofs? Are these usually combustible and flammable?
3. Do you see any trends that the quality of the components that belong to the PV system have been getting worse over the last years? (Not focusing on the effectiveness in electric power, but the sustainability, safety, and robustness)

### Email from the Swedish Civil Contingencies Agency

Q:

> [..] I am especially searching for photos, statistical tables or similar. The photos are preferably visualising how these are fire damaged, for example, fire damaged MC4 connectors, damaged PV modules, cables etc. Do you have such photos in your archives? I am mainly thinking of your database, “Learning from accidents”. Perhaps there is something there?

R:

> We do not have many accident investigations about fires in PV systems. We lack photos since we have not performed any investigation of this kind of fire ourselves.

### Email contact with fire department A

### *Translated and transcribed in accordance with the answers from the email respondents.*

R:

1. We have not been investigating this on our own, but there is research that has been performed by RISE, showing that switches, just after the inverter can cause arcs and initiate a fire. With this background, we have updated our guidelines regarding switches on roofs with solar panels. Instead, we have asked for the function to have as much as possible without electricity to not block any new solutions.
2. Based on my knowledge, we have not had many incidents where it was confirmed that the fire had started in the solar panels or in any connected component, so that question is hard to answer. The problems that can be caused by solar panels is a reradiation onto the roof (depending on the angle), difficulties to reach and make holes for fire breaks and the risk for electric shocks on firefighting personnel if the cables are not powerless. […].
3. I do not have any experience about this question, and I cannot comment on either one or the other part.

## Email contact with fire department B

### *Translated and transcribed in accordance with the answers from the email respondents.*

R:

> Even if the fires regarding this certainly will increase in the future, we have not a much. We have done a search in our systems and the results are few. One incident involved an inverter, and it only says very short in the report that “it seems that the fire has started where the DC cable enters the inverter”. So, on the first question we have too small amounts of data to be able to answer. We know that in Australia, they have had problems with DC switches, which they thought would cease the risks, but instead appeared to be the most common fault causing a fire. For the second question, the answer is the same, too small amounts of data. [..]. Over time the answer to the third question will more easily relieve itself, but not as it is right now. [..]

## Email contact with fire department C

R:

> - According to our accident investigations, we have seen that several fires have started close to switch before the inverter. It has also been fires on the roofs in connection with the solar panels.
> - We have not had any larger incident. The fires have been limited in connection with the solar panels on the roofs and with direct connection with the switch.
> - Nothing that we have been able to read since the statistic basis is limited.

## Email contact with fire department D

Q:

> Hi,
>
> […] I have been in contact with […] at the Swedish Civil Contingencies Agency (MSB) and he recommend your report “Fire in switch in PV system in Vänersborg”, Ulrik Olsson, accident report G2022.122318. I would really like to use the photos that are in your report on components caused by fire. Is that okay? Of course, I will refer to the report.

R:

> Hi!
> You have my permission to use the photos in your work. You can refer to Närf.
> /Ulrik