Building-integrated photovoltaics in Norway, challenges and standards

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Preface

This master's thesis puts an end to a two-year study program in Renewable Energy Systems at the University of Oslo. The thesis represents 30 credits and the topic was developed in collaboration with Norsk Elektroteknisk Komite (NEK).

The thesis has been written during the COVID- 19 pandemic 2021. Writing a master's thesis is challenging even under normal circumstances, however COVID- 19 has made an impact on my research. Despite this situation, I have experienced great support and willingness to help from many people. First, I would like to thank my supervisors, Sabrina Sartori and Kristin Fagerli for good input, advice and discussions throughout the master's process.

Further, I would like to thank the persons that have taken part in the interviews and have contributed with their knowledge, experiences and reflections related to the thesis problem statement.

In addition, I want to thank my fellow students, friends and family for the support they have given me through these years. I would especially like to thank those who have given me invaluable help in the final editing stages, Elizabeth Ellingsen and Inger Kristine Løge. A special thanks to my partner Ross Ellingsen - who has been a pillar of support and conversation partner throughout the process.

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Kristine Fuglestad

Kristine Fuglestad

Abstract

This research is a mapping study looking at todays situation of building-integrated photovoltaics (BIPV) in Norway, investigating technological challenges and how standards can help ensure access to the solar energy market. The research was developed in collaboration with Norsk Elektroteknisk Komite (NEK) to map future work goals for the company's internal committees dealing with solar cells and solar cell installations. A qualitative study has been carried out where technical challenges, social challenges and standards within BIPV have been explored.

Climate challenges and the green shift are current trending topics constantly being discussed. BIPV is a solution to help solve these challenges. BIPV replaces conventional building materials such as tiles, shingel and slate which can lead to cost savings depending on the BIPV technology chosen. The majority of the actors working in the industry believe that this technology will increase in market share as soon as more people become aware of the existing opportunities.

The findings indicate that BIPV is challenging because it is a combination of construction and electrical technology. A more thorough systematic process and collaboration at a more detailed level between the actors are required. The most important challenge of BIPV technology concerns responsibility, since BIPV falls between two areas of expertise. There are no clear guidelines on what must be done, and who is responsible if a problem arises between the electrical and the building technology.

Availability of standards is not good enough. This is not because the standards do not exist, but because they are difficult to find. A simplification system that brings out the most important standards has been requested by several actors in the industry. This will make it easier for the users of standards, and it will help ensure access to the solar energy market.

Sammendrag

Denne forskningen er et kartleggingsstudie for å se på hva som er status på bygningsintegrerte solceller (BIPV) i Norge i dag ved å utforske teknologiske utfordringer, og hvordan standarder kan bidra til å sikre markedsadgang til solcellemarkedet. Forskningen ble utviklet i samarbeid med Norsk Elektroteknisk komite (NEK) for å kartlegge fremtidige arbeidsmål for selskapets interne komitéer som jobber med solceller og solcelleinstallasjoner. Det har blitt foretatt en kvalitativ studie der det er sett på tekniske utfordringer, sosiale utfordringer og standarder innenfor BIPV.

Klimautfordringer og det grønne skiftet er temaer som stadig diskuteres. BIPV er en løsning for å bekjempe disse utfordringene. BIPV erstatter konvensjonelle byggematerialer som for eksempel takstein, shingel og skifer, noe som kan føre til kostnadsbesparelser avhengig av hvilken BIPV teknologi som blir brukt. De fleste i bransjen har stor tro på at dette er en teknologi som kan bli stor i Norge så fort flere blir gjort oppmerksomme på mulighetene som finnes.

Funnene tyder på at BIPV er utfordrende fordi det er en kombinasjon av byggeteknisk og elektroteknisk. Det kreves en mer grundig og detaljert planleggingsprosess, og et samarbeid på et mye mer detaljert nivå mellom de ulike partene. Den viktigste utfordringen til BIPV teknologien gjelder ansvar, siden BIPV både er elektrofag og byggfag. Det finnes ikke klare retningslinjer på hva som må gjøres, og hvem som har ansvar om det oppstår et problem mellom det elektriske og det bygningsmessige.

Angående standarder ser det ut til at tilgjengeligheten ikke er bra nok. Dette er ikke fordi standardene ikke finnes, men fordi de er vanskelig å finne frem til. Et forenklings system som får frem de aller viktigste standardene er blitt etterspurt av flere aktører i bransjen. Dette vil gjøre det enklere for brukerne av standardene, og det vil bidra til å sikre markedsadgang for solcellemarkedet.

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Symbols

I	Current
Isc	Short Circuit Current
V	Voltage
Voc	Open Circuit Voltage

Abbreviations

AC	Alternating Current
AM	Air Mass
BAPV	Building Attached Photovoltaics
BIPV	Building Integrated photovoltaics
BOS	Balance Of Systems
CdTe	Cadium Telluride
CENELEC	European Standards Organisation
CIGS	Copper-Indium-Gallium-Diselenide
CE	Conformité Européenne
DC	Direct current
DSSC	Dye-Sensitized Solar Cells
EEA	European Economic Area
FF	Fill Factor
IEC	International Electrotechnical Commission
IR	Thermal Imaging
ISO	International Organization for Standardization
JWG	Joint Working Group
MLC	Module Level Converter
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MTTF	Mean Time To Failure
NEK	Norsk Elektroteknisk Komite
NOCT	Nominal Operating Cell Temperature
NSD	Norwegian Centre for Research Data
PV	Photovoltaic
STC	Standard Test Conditions
TC	Technical Committees
UV	Ultraviolet

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1 Introduction and Overview

1.1 Background

The Norwegian landscape contributes to making hydropower the main source for renewable electricity production. With 1681 hydropower plants [1], around 90% of the electricity produced in Norway comes from hydropower [2]. The total energy production was 154,2 TWh in 2020, with a total installed capacity of 37 732 MW. There is a significant interest in increasing the diversification of renewable energy sources such as wind and solar in Norway [1].

Photovoltaics (PV) is a promising renewable energy technology designed to contribute to overcoming the global energy crisis. The use of solar energy is steadily growing in market share and is in many countries becoming the cheapest source of electricity. In 2019 the total global installed capacity reached 623 GW, of which 112 GW from installation of PV power systems [3].

A country like Norway with varying climatic conditions and a nordic climate might not seem ideal for solar panels. The irradiance in Norway is significantly lower than in countries closer to the Equator, never the less this cold environment actually favours solar PV. A cold climate will increase the photovoltaic output, consequently increasing the voltage which makes the cell generate more electricity [4].

Solar PV technology is increasing in Norway and the majority of this growth can be found on building roofs, while the ground mounted panels dominate in many other countries. The typical way of mounting the panels is to put them on an already existing roof, which are referred to as building-attached photovoltaics (BAPV). There is now a growing interest in building-integrated photovoltaics (BIPV) where the panels get implemented into the building itself as a part of the building envelope [5]. This technology allows the structure of the building, roofs and windows to generate electricity and thereby reduces the net load of the building.

1.2 Motivation

There is a great international effort to make buildings more sustainable, but there are several things that must be in place to achieve this. In Norway, BIPV is an attractive technology in regard to goal achievements in climate policy, power production and Norwegian business and industry [6].

In Norway, solar panels are mostly installed on roofs. BIPV is very synergistic and has endless possibilities. Roofs and facades are being replaced by conventional building materials so that material use and money can be saved. Energy and climate footprint are also important factors here [6]. Aesthetics, quality and variation are also important to attract more architects to use this technology. The ability to customize modules to each project makes this technology very attractive to several actors in the industry.

This thesis will take a closer look at the challenges with BIPV in Norway and examine what is needed for this technology to become more widespread. Technical challenges, soft challenges and standards will be explored in order to answer the problem statement. There seems to be little research in this area so more in-depth research within BIPV is necessary to find out how its implementation can be efficiently accelerated. It is also interesting to understand what several actors in the industry see as their biggest challenges, and what must be done to overcome these.

1.3 Problem Definition

The purpose of this thesis is to look at challenges and standards related to BIPV in Norway. BIPV is an evolving technology and the thesis will investigate how it can become more mainstream. The problem statement of the thesis is:

What are the challenges for BIPV technology in Norway and how can standards help ensure its access to the solar energy market?

In order to be able to answer the problem statement, three research questions have been developed and formulated:

Q1 What are the technical difficulties related to BIPV technology?

Q2 How can knowledge, social and political influence affect the implementation of BIPV in Norway?

Q3 What role do standards play in the development of BIPV technology?

1.4 Thesis structure

Introduction and Overview
The first section covers background and motivation, along with the problem statement for the thesis.

Theory and Literature
This section includes the theoretical framework of the thesis. It covers the PV system, standards and state of the art.

Methodology
This section covers the methodology chosen to answer the research questions. It gives the reader insight into how the data has been collected.

Results
This section presents the findings from the methodology chosen.

Discussion
This section discusses the findings and compare them against each other.

Conclusion
The last section answer the research questions and includes recommendations for further work to the topic introduced.

2 Theory and Literature

2.1 PV cell and its characteristics

A solar cell has the advantage that it directly converts sunlight into electricity. The technology is based on the photovoltaic effect, hence the name. It is an electronic device where irradiance from the sun produces a current and a voltage when shining on the solar cell. In order for the solar cell to generate electricity it has to follow three requirements. Firstly, it needs a material which makes the absorption of light kick an electron to a higher energy level. Secondly, it needs to separate the energy carriers and thirdly the electrons need to be transported to an external circuit. This conception is illustrated in Figure 2.1. The most common materials used for solar cells are semiconductor materials [7].

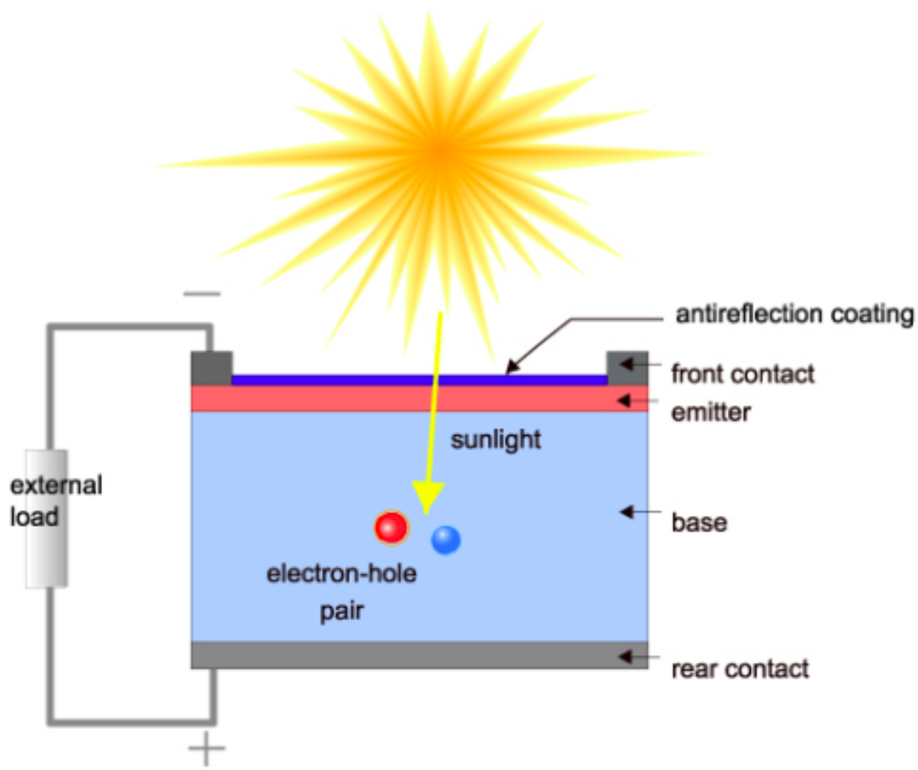

Figure 2.1: *Basic conception of a solar cell [7].*

The energy carried in the photons from sunlight is absorbed by electrons in the material of the system, and this is how the sunlight is converted to direct current. Solar cells are the smallest building block of solar PV systems. This is the device where the photovoltaic effect takes place and the electricity is generated. The top layer is made of an antireflection material that contributes to keeping more of the sunlight within the cell and therefore promoting more of the photovoltaic effect. Under the antireflection layer there is a semiconductor consisting of a p-n junction. This is made of a thin top layer of silicon doped with an element with a higher number of electrons than silicon, such as phosphorus, which creates a negatively charge region. Underneath there is a thicker layer of silicon doped with an element with fewer electrons than silicon, for example, boron. This positive charged region is then connected with the negatively charge region with the use of a conductive metal. This creates a flow of electrons between the regions resulting in an electric current [8]. The structure of a solar cell is illustrated in Figure 2.2.

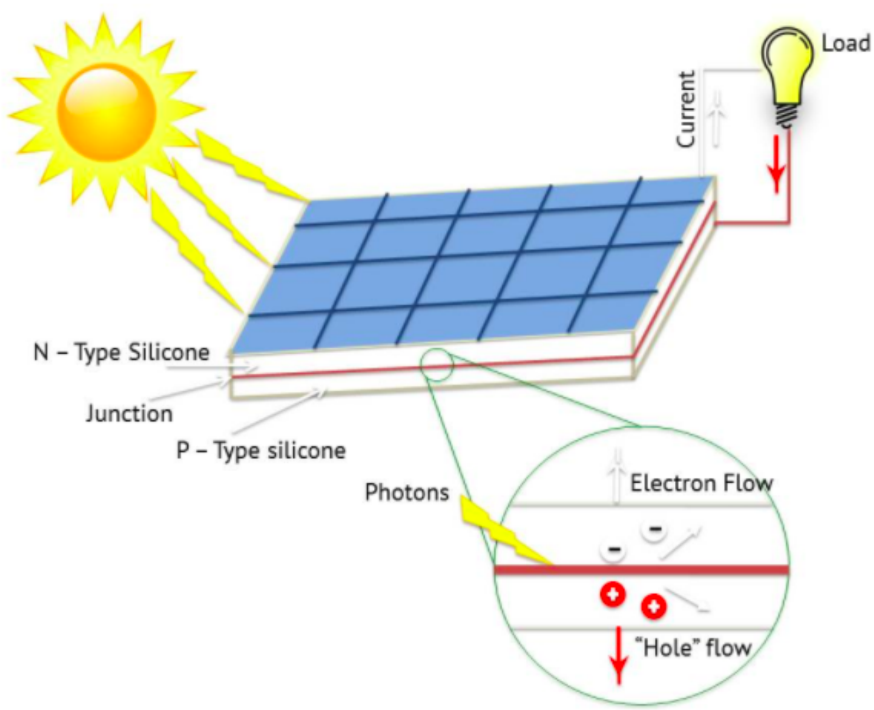

Figure 2.2: *Structure of a solar cell [9].*

2.1.1 Standard test conditions

Standard test conditions (STC) are the industry standard under the conditions where the solar modules are being tested. The solar modules can be compared accurately against each other by using a fixed set of conditions. The standard test conditions include:

- A cell temperature of 25°C. This includes the temperature of the solar cell itself, not of the surroundings.
- Solar irradiance of 1000 W/m^2. This indicates the amount of sunlight falling upon a given area at a given time.
- Air mass of AM1,5. This specifies the amount of sunlight that passes the earth's atmosphere before it reaches the surface [10].

2.1.2 Nominal operationg cell temperature

Nominal operating cell temperature (NOCT) is used in order to pay more attention to the conditions of the solar modules in reality and the changes that occur in the cell at different temperatures. This estimate is given under specified operating conditions where:

- Ambient temperature of 20°C.
- The solar radiation is at 800 W/m^2.
- Wind speed of 1 m/s.
- The module is mounted on an open rack at 45 degrees [10].

2.1.3 Efficiency

The efficiency of a solar cell is defined as the ratio of energy output from the solar cell divided by the energy from the sun. This parameter is used when comparing different solar cells. The efficiency is dependent on the temperature of the solar cell and the intensity and the spectrum of the incoming sunlight. Terrestrial solar cells are measured under STC with AM1,5 and a temperature of 25°C [11]. The efficiency is often given in percentage, which indicates that if a solar cell has 20% efficiency, it's capable of converting 20% of the irradiance into electricity. When operated under conditions with strong irradiance, monocrystalline silicon cells have the highest efficiency compared to other cells used in terrestrial PV systems. Other cell materials may operate better in weak or diffuse sunlight [12]. When taking a module into consideration, it has a slightly lower cell efficiency. The module's surfaces are not effectively filled with cells and it is common for modules to have a frame covering the front [12].

2.1.4 PV cell material technologies

The cells can be classified as first, second and third generation solar cells. An illustration is shown in Figure 2.3. The first generation silicon solar cells have been dominating the market, and still have a market share of over 80% [3]. Crystalline silicon can further be divided into single crystal and polycrystalline silicon. The second generation solar cells refer to the thin films. The most common thin film solar cells are amorphous silicon, Cadium Telluride (CdTe) and Copper indium gallium selenide (CIGS) [13]. The third generation solar cells include dye-sensitized solar cells (DSSC) and organic or polymer solar cells [14].

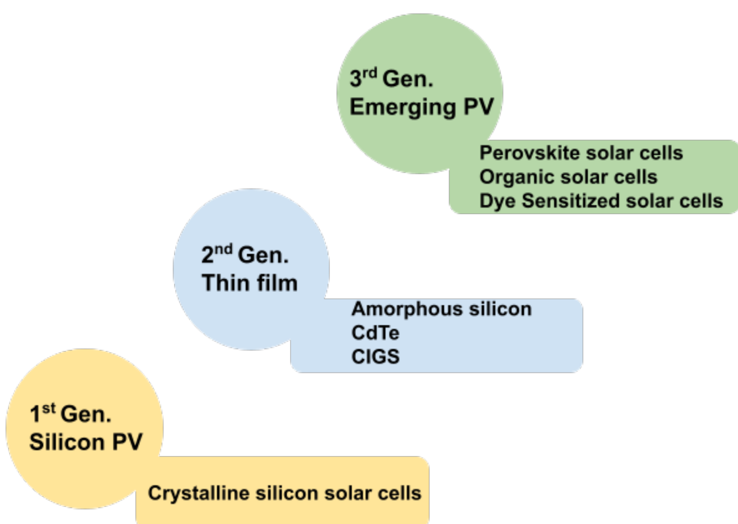

Figure 2.3: *PV cell material technologies.*

2.2 Maximizing the output power of the PV cell

A solar cell generates a voltage (V) and a current (I) output when illuminated. Desired voltage and current are achieved when connecting solar cells in series and parallel, respectively [15].

The solar cell output is limited by the open-circuit voltage (Voc) and the short-circuit current (Isc) for a given temperature, irradiance and area. The maximum value of the product of Vmp and Imp is known as the maximum power point (MPP). This is the point where the solar cell should operate at in order to obtain the best possible output of the cell. This can be illustrated graphically by the largest rectangle under the IV-curve seen in Figure 2.4 [15].

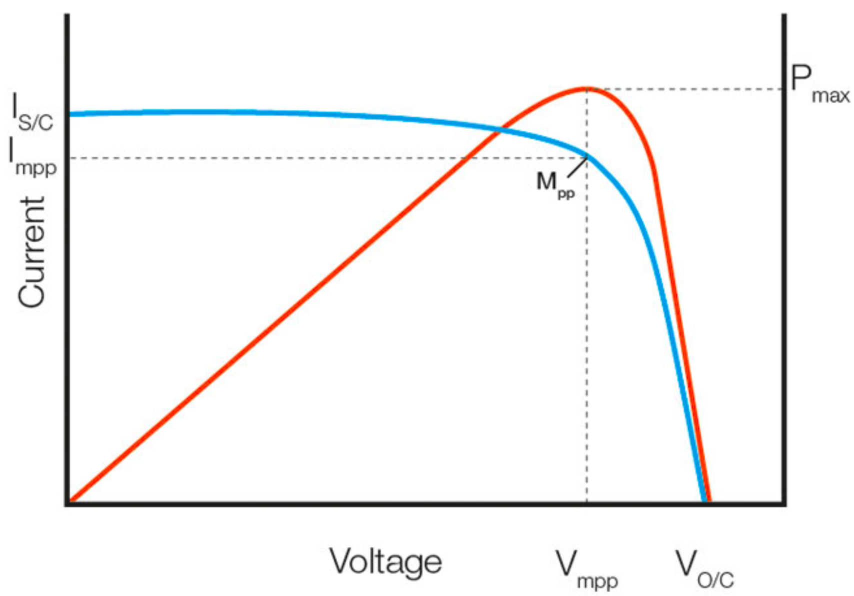

Figure 2.4: *Graphically illustrated maximum power point [15].*

<u>Short-Circuit current</u>

The Isc is the current that is supplied from the solar cell when it is short-circuited, resulting in a voltage across the solar cell which is equal to zero. This is therefore the largest current which can be obtained from the solar cell. It occurs due to carrier generation and collection within the cell [11].

Open-Circuit voltage

The Voc is the voltage that occurs when the current in the solar cell becomes equal to zero resulting in the maximum possible voltage a solar cell can deliver. The photogenerated current and the saturation current is dependent on this parameter. As discussed in the next paragraph, the Voc is negatively affected by an increasing temperature [11].

Fill factor

The fill factor (FF) is defined as the ratio between maximum power generated by the solar cell divided by the product of Isc and Voc. It's function is to describe how close the characteristics of the IV curve is to the ideal rectangle form in Figure 2.4. This would be the area to the largest rectangle that fits within the IV curve [11].

2.2.1 Effect of temperature and irradiation changes

The cell temperature will affect the open-circuit voltage, and as the temperature increases due to heat generated by internal power dissipation or environmental changes, the open-circuit voltage will decrease illustrated in Figure 2.5. This will make a significant impact on the power output and will shift the IV-curve to the left. It will have a major impact on the open-circuit voltage and a minor increase in short-circuit current [15].

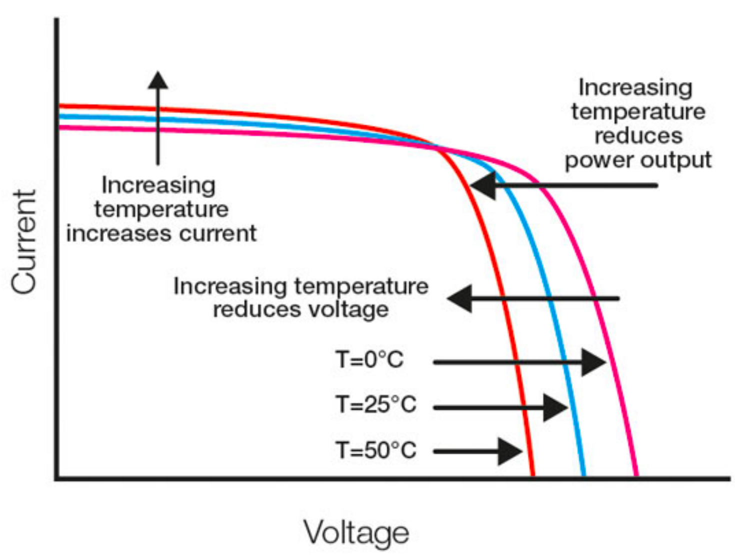

Figure 2.5: *The effect of increase in temperature [15].*

The irradiance will also affect the performance. A reduction of sunlight will result in a reduction in short-circuit current and a minor change in the open-circuit voltage [16]. This is illustrated in Figure 2.6.

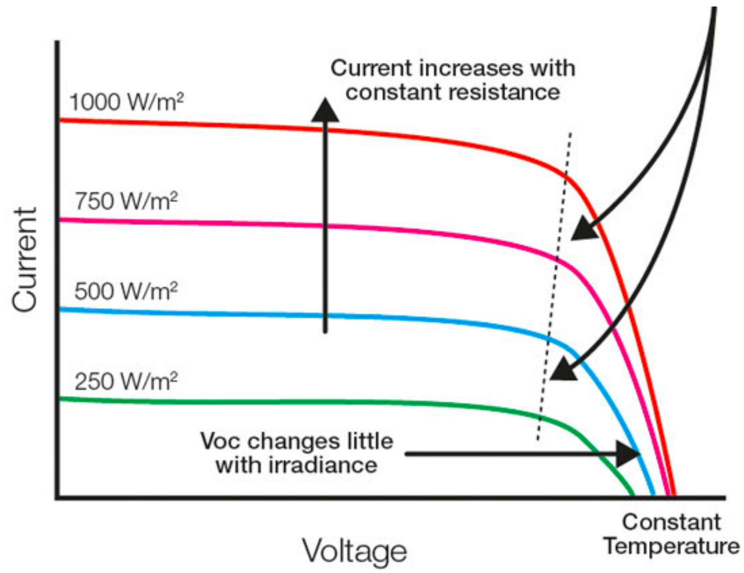

Figure 2.6: *The effect of decrease in irradiation [15].*

2.3 PV modules

A single solar cell has a limited output, so it is common to connect several solar cells into a solar module to obtain a higher power generation capacity. The individual solar cell only produces a small amount of voltage – less than 0.5 V. By connecting the cells together in a series, the module is able to produce a much higher voltage. Normally a module consists of 60 cells producing 270 - 350 W, but it is possible to connect a higher number of cells in each module [16]. Depending on the electricity demand the modules can also be connected in strings and arrays. Strings are referred to as series connected modules, whilst array refers to parallel connected strings [17]. Figure 2.7 illustrate the difference between cell, module, string and array.

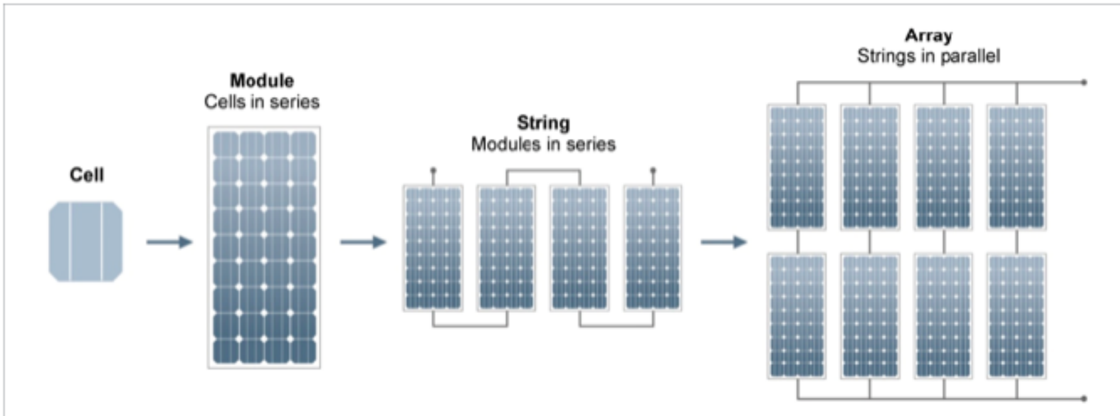

Figure 2.7: *Illustration of cell, module, string and array [17].*

Connecting the solar cells into modules is a necessity in order to protect them from the environment and prevent mechanical damage and corrosion. The module is made in several layers. The solar cells are encapsulated on the top and bottom to keep them adhered to each other and the top and bottom layer. On top of the solar cells there is a protective glass and frame to provide strength and durability. The backsheet is also made to assure efficiency and to keep the cells undamaged [16]. The typical structure of a PV module is shown in Figure 2.8.

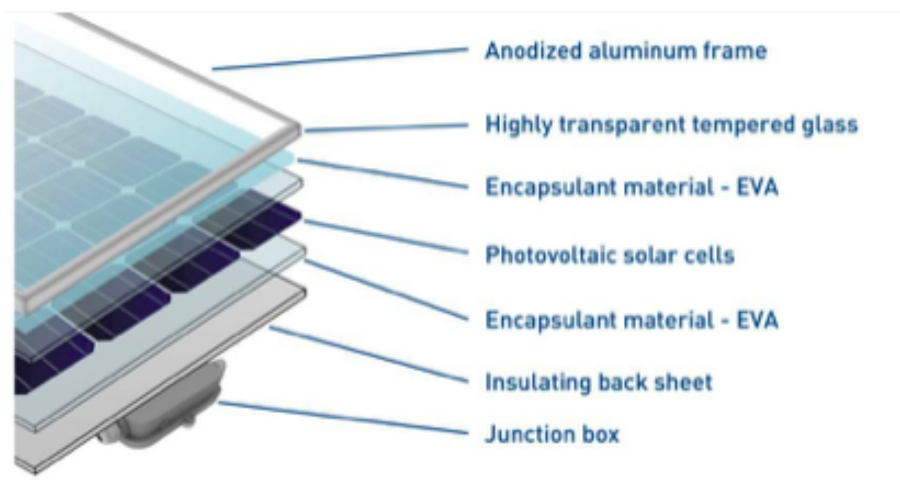

Figure 2.8: *Common PV module structure: frame, glass, encapsulant, solar cell, encapsulant, back sheet and junction box [18].*

2.4 PV degradation and failures

PV modules are often known for their reliability and are designed for faultless operation. However, issues regarding degradation of the performance or damage to the module can occur when the solar module is exposed to the outdoor environment for a certain period of time. A reliable module has to operate within the performance guaranteed along with delivering the expected electrical output [19]. A warranty of 25-30 years lifespan is common for crystalline PV modules, however the performance will degrade over time. This has led to a guarantee of 80% effective modules after 25 years which assume a degradation of 0,5-3% each year [20].

The definition used to explain a PV module failure in this thesis is defined by the International Energy Agency Photovoltaic Power Systems Programme (IEA-PVPS). They state that: "A PV module failure is an effect that (1) degrades the module power which is not reversed by normal operation or (2) creates a safety issue" [19]. Common failures of products are divided into three categories: infant-, midlife- and wear-out failures illustrated in Figure 2.9 [19].

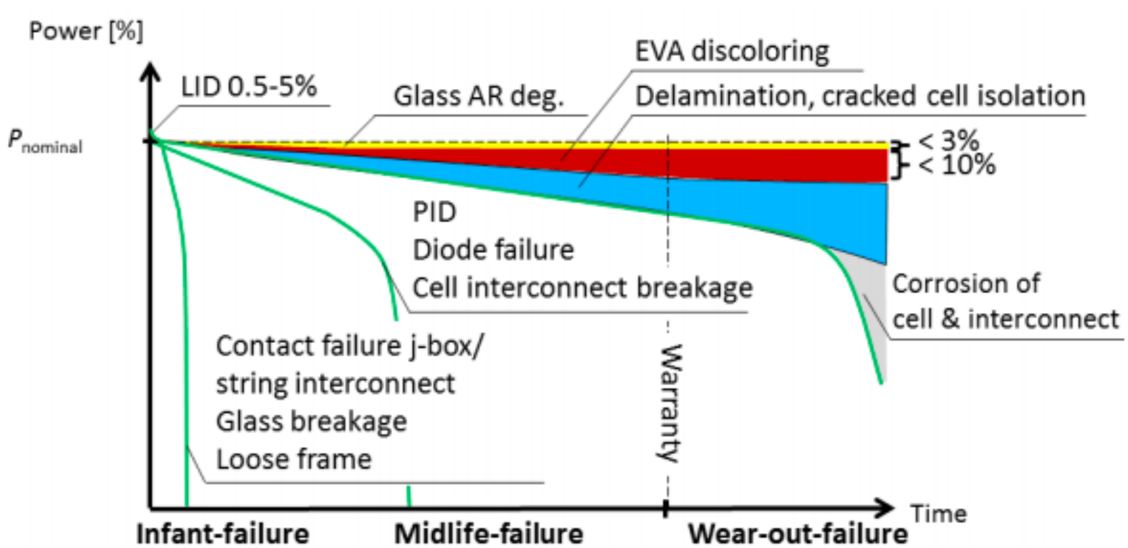

Figure 2.9: *Common failures for crystalline Silicon PV modules [19].*

2.5 Grid-connected PV systems

PV systems can be divided into stand-alone systems which are self-sufficient and grid-connected systems. The stand-alone PV systems were mostly used in the beginning of the PV industry installations. The market started shifting in the 1990s and today most of the PV installations on buildings and the PV power plants are grid-connected. The advantage of this technology is that the electricity grid and the PV system cooperates. If the PV panels produce more electricity than needed, the surplus will be fed into the grid. Electricity can also be imported from the grid when more electricity is needed [21].

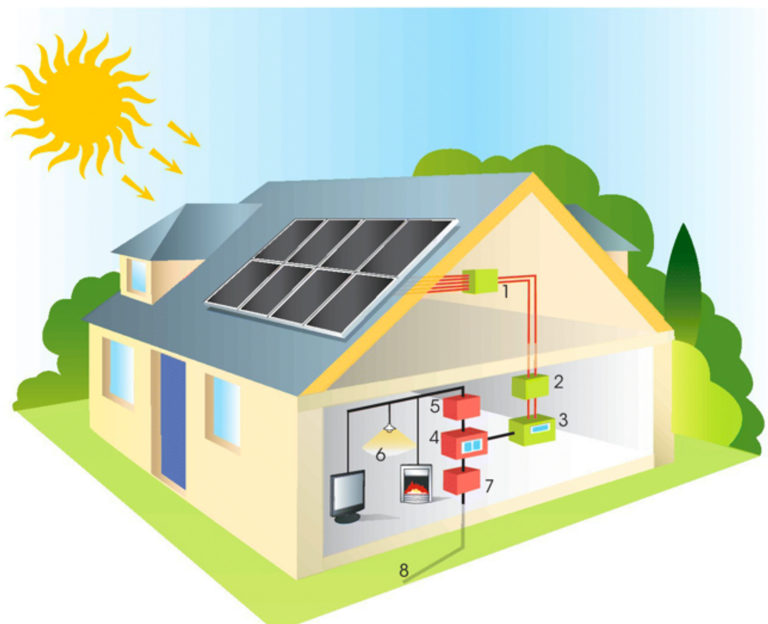

Figure 2.10: *Grid-connected domestic PV installation [21].*

The numbers in Figure 2.10 reflect different functions that will be explained.

1. PV combiner unit: This connects the modules and operates as a junction box.
2. Protection unit: Including switches on the AC and DC side to protect against lightning.
3. Inverter: Converts DC power into AC power.

4. Energy-flow metering: Records the flow of electricity in kWh.
5. Fuse box: Regular fuse box.
6. Electrical loads: Includes heaters, lighting and Tvs.
7. Junction box: Connects the house to the utility supply cable.
8. Junction box: Connects the house to the utility supply cable [21].

2.5.1 BOS

A grid-connected PV system includes components that are called balance-of-systems (BOS), and they refer to all components in the system except the PV panels itself [22]. Even though the cost of solar panels has declined over the past years, BOS components still account for around 50% of the total system costs. The prices of BOS might also get reduced slightly due to a continuous growth in the PV market which will affect economies of scale [21].

2.5.2 Inverters

The inverters play a major role in both grid-connected and stand alone systems, translating the generated DC current from the panels into AC current. AC power is most used to run electrical appliances [23]. Advanced electronics assure that this happens at a correct frequency and voltage in order to match the grid supply [24]. The inverters come in different sizes depending on the PV system size and the maximum load demand [23]. The efficiency of the inverters varies but can get as high as 98%. The warranty of the inverters is usually within a period of 5 to 15 years, but some companies even offer a warranty of 20 years [24].

BIPV modules are installed during the construction phase, and therefore the electrical installation will be more important to plan with this technology. To minimize installation time and engineering effort, it is important to consider the way the inverters and the modules are inter-connected [25].

There are different possibilities for the electrical installation of the BIPV system.

1. String inverter
2. Micro-inverters
3. Series power optimizers
4. Parallel power optimizers

String inverters includes several modules that are series-connected to form a string, and these are coupled to the string inverter. The maximum power point tracking (MPPT) is done per string, and several strings are possible per inverter. Micro-inverters has one inverter coupled to a single module, and the MPPT is done per module. The output is then directly coupled to the AC grid. Series power optimizers also has one converter per module, but the difference is that the output will be DC. A central inverter will then contain the output ports of multiple converters that are connected in series. Parallel power optimizers also have a DC output, but in this case the DC voltage is higher. The optimizers are parallel connected to the same DC bus, and the MPPT is done per module here as well [25].

Partial shading is more prevalent in BIPV systems than in other PV systems. In order to limit this problem, a micro-inverter (DC/AC) or power optimizers (DC/DC) are a preferred solution. This will also introduce a MPPT on each module, not per string only. If partial shading is not an obstacle, it will be more convenient to use a string inverter from a cost perspective [25]. An integrated module level converter (MLC) should be implemented into the BIPV module to increase the flexibility of the installation. The MLC will be placed at the rare of the module or inside the metallic framework. The drawback of this solution is that the inverter is difficult to reach after the installation is finished. Repair and replacement therefore becomes very tricky or even impossible [25].

It is important to carefully consider the lifetime of the MLC, as it should be similar to the module or even the lifetime of the facade. According to reference [26], the mean time to failure (MTTF) is approximately 20 years for string inverters, while the mico-inverters has a MTTT of 300(+) years [27]. However, failures in the inverters might occur, even though special care is taken. The advantage of the MLC is that it will only affect the specific module connected to the inverter that has failed. The power generation will therefore be affected, but the system as a whole will be operating. This applies to both the micro-inverters and the parallel power optimizers. Regarding series power optimizers, a small fault could affect the entire string [25].

2.5.3 Cabling

Cables are needed in order to transport electricity generated by the solar module. The cables commonly used from modules to inverters are water and UV resistant and have double insulation. They also have to withstand mechanical stress, chemical stress and both low and high temperatures [28]. The the voltage drop should be kept low within the cables. High system voltages and long module strings are recommended for reducing the current going through the cables. This is done as a result of the power loss being proportional to the square of the current [21].

2.5.4 Building-attached photovoltaic modules

Building-attached photovoltaic modules have to be mounted on a building envelope, so they are integrated into the building after the construction is finished. It has not any additional functioning except from generating electricity [29]. The majority of the PV installations on buildings today are BAPV [30].

2.5.5 Building-integrated photovoltaic modules

Building-integrated photovoltaic modules replace conventional building materials, usually the building envelope like the wall, roof or the glazing. An important criteria is that it should provide one or more functions to the building envelope compared to BAPV. It has to act as a device to generate electricity as well as being a part of the building functionality [29].

The beauty of BIPV is that it can be implemented into the starting process of a new building and it is very flexible in terms of design. The main goal of implementing more PV is to improve the human environment, however the implementation of BIPV adds many advantages due to it being very flexible [21].

BIPV has many advantages in addition to the aesthetics. Building facades and rooftops can be replaced by BIPV, which might lower the investment cost by using this technology instead of conventional building materials. It does not need to take into account additional land, as it can be a part of all types of buildings even in populated cities. Transmission losses get reduced due to the generated electricity being generated on-site [21].

PV installations can be seen as something found "outside" since they have to collect sunlight in order to generate electricity. Flat roofs can be slightly more hidden than sloping roofs and building facades. The environmental declaration states that any PV arrays in public should be appealing to people passing by, as well as owners and users of the building itself. Some PV installations might also be seen from the inside of a building, and in this case this is usually preferred from the architects in order to be inspiring and give satisfaction. Modules can be designed to provide ventilation or shading needed on the building [21].

2.6 Standards available

2.6.1 What is a standard?

A standard is designed to be used as a definition, a rule or a guideline and can be found on a technical document [31]. Starting from an idea to a complete standard, this process is called standardization. Standards can be found everywhere. The entire society is built on this concept. It makes everything more convenient, and it advertises innovation. By using the same starting point, it gets easier to make society a safer and a more sustainable place to live [32].

Standardization is not something controlled by the government, but rather a cooperation between the private and the public [32]. It is a work that takes place in projects. The project could work on revising an existing standard or establishing a new standard based on demands in the market. When a new technology is entering a market, this could increase the need to revise some already existing standards. The organization of establishing or revising a standard is found on a national, European and international level [33]. A standard is voluntary to use, but the reason for having them is to create good tools for the industries to use. It contains detailed requirements to ensure that a high level of safety can be achieved [34].

2.6.2 NK 82

NK 82 is a Norwegian standards committee based on electrotechnical standardization and electrical safety related solar PV energy systems. It deals with national, European and international standards. This committee has to cover everything in the PV energy system, including irradiance to the PV module to feed electricity into the grid. The amount of solar energy implemented in Norway and in the rest of the world is growing, which makes it important to achieve standards with good quality and that they are being used by the sector. NK 82 is now working with translation of the European and International standards for PV, in order to make the standards more convenient and available for the Norwegians [35].

The standard collection NEK 400:2018 is linked to low-voltage electrical installations in Norway. It is not a requirement that the collection must be used, but by referring to it, you meet the authorities' expectations of electrical safety. A new edition of the collection of norms comes every fourth year [36].

2.6.3 CENELEC TC 82

CENELEC is the European Standards organisation covering the electrotechnical field. They develop standards that will support the development of a European market that will facilitate trade between countries, create new markets and cut compliance costs. The committee also promotes innovation and competitiveness, and through the production of voluntary standards, they also make technology available industry-wide [37]. CENELEC has to cooperate with other European National Committees translating international standards into national ones [38].

2.6.4 IEC TC 82

IEC is the international electrotechnical commission and was founded in 1904. It covers all standards aspects within the electrotechnical field. To deal with the PV energy systems, IEC TC 82 was established in 1981. The growing demand worldwide of PV products has seen an increase after the publications of the standards with more than 129 publications. Within IEC, TC 82 has the largest work-programme and is seen as the most active technical committee. The committees have the responsibility for maintenance of already published standards, in addition to developing new standards needed. Organisations with knowledge about existing standards and future research on the topic have to come with inputs when dealing with new or existing standards [38].

2.6.5 Harmonized standards

A harmonized standard is a European standard that is developed by CEN and CENELEC, the European standardization organizations. It is a technical specification and it is supposed to satisfy basic safety requirements considered by the EU/EEA. When testing a product using harmonized standards it is assumed that it will meet the basic safety requirements. If using other technical specifications, this product needs to be documented to meet the required safety level [34]. CE marking is found on several products traded in the European Economic Area (EEA) and verifies that the product is considered to meet EU safety, health or environmental requirements of the authorities. This will ensure market access of products within the European market. CE marking does not indicate that products were made in the EEA, but it confirms that products have been assessed before being accepted on the market [39].

2.7 Latest development in BIPV technology

The following section describes the current research that is being done regarding technical challenges and standards for BIPV.

2.7.1 Analysis of the BIPV market

The building sector presently consumes 40% of energy annually when looking at the global perspective, which is mainly due to heating and cooling. The world energy consumption is expected to increase up to 50% in 2035 when compared to 1990 due to an accelerated population growth and urbanization. This shows the necessity of an increasing market penetration for renewable energy, where solar energy will play an important role for this implementation [40]. The BIPV market is currently relatively small and the prices are high compared to BAPV. However, there is significant expected growth in this technology in the years come. The prices for solar cells have dropped considerably in the past few years which will influence the implementation of more BIPV [41].

The status report 2020 about BIPV states that the market perspective for BIPV looks promising and that it has reached a high level of maturity. BIPV is a powerful technology when it comes to making cities rely on more renewable energy and it is now ready to be fully integrated into the construction market. It also mentions how many barriers within this technology that have been solved, and what is still remaining as being challenging. It seems to be difficult to establish a demonstration of BIPV in real buildings that can ensure reliability, durability and performance when considering cost competitiveness [42].

The analysis presents three different classifications of BIPV products:

- Glazed semi-transparent BIPV solution with thermal properties.
- Opaque glazed BIPV solution without thermal protection.
- Opaque no glazed solution without thermal protection [42].

Glazed semi-transparent BIPV solution with thermal properties

These transparent modules are mostly being used as skylights and curtain walls. They will get integrated onto roofs and facades adding multi-functionality to the building. The modules are also customizable in dimension, transparency, colour and shape. These products can also be used as partitions, parapets and balconies, etc. Thin film technologies dominate this category [42].

Opaque glazed BIPV solution without thermal protection

Rooftop tiling, facades and rainscreen solution require opaque claddings and they need to provide durability, environmental protection and good aesthetics. The term opaque means that light is not allowed to pass through [43]. They need to assure thermal protection and ventilation of the building, and these modules can also be customizable in size, shape and colour. Crystalline silicon technology dominates the market for this category [42].

Opaque no glazed solution without thermal protection

The main advantage of these modules is that they can be curved so they are very flexible. Thin film technologies are mainly used here, such as CIGS, where they are encapsulated in polymers or metals to make them bendable and light [42].

2.7.2 BIPV standardization

BIPV must take into account two different standardization and regulation schemes, one related to the building industry and the other one to the electrical industry. The scheme regarding requirements of the building industry can be regulated in international (ISO) standards and local building codes. The electrical industry refers to the international (IEC) standards in addition to local regulations. International standards in the PV industry require testing of all products by laboratories and testing centres. One thing remaining for the BIPV standardization is harmonized standards for testing of these specific products [44].

In 2016, the first BIPV standard EN 50583 was published. This was the driver for continuous work on BIPV and standardization. The information given in this standard is missing some important information. Technical requirements for building integration is an example. The information provided should be more defined, resulting in a more sufficient comparison of the various products. Additional qualities such as durability and reliability should also be a part of the standard [44].

Regarding the building industry, there are many standards that can relate to the BIPV products. The major problem is deciding on which of the standards should be obligatory or optional. Standards covering different scenarios related to safety should be of high priority. A second priority could be a standard covering resistance to rain penetration. There is clearly a high demand for further development and work on getting more harmonized standards. Another issue is that the BIPV standard EN 50583 is not well known in the building industry. BIPV products should be implemented into catalogues regarding construction products as well as in planning tools. This will help promote this technology in the construction sector [44]. As of 2021, a decision has been made that a new working group, Joint Working Group (JWG) 11 will start working with standards on BIPV that will cover several topics related to this technology. This group will be responsible for IEC 63092 and ISO 18178 series [45].

2.7.3 Reliability

A slow market development regarding BIPV can also be explained by the reliability of the products available. As of this moment, there seems to be little cooperation between the PV industry and construction industry when it comes to product optimization and application. The PV technology itself is quite established, but experience is lacking when it comes to optimization of these products with a construction aspect. This shows again the importance of developed standardized procedures that can easily evaluate different products to specific applications [44].

2.7.4 Aesthetics

The aesthetics of BIPV may be rather important as it allows for coloured modules that make the building more attractive, but this will also have a negative impact on the efficiency. The fact that these modules can get integrated into the building and replace conventional building materials also make this technology very attractive. By increasing the flexibility of different shapes and sizes of the BIPV modules in addition to reducing the complexity of the mounting systems the aesthetics of the building itself may be enhanced [44].

2.7.5 Availability

Another disadvantage of this technology is the limited availability of products on the market. A lack of large companies selling these products makes it difficult to implement it into the planning process. Problems arise if it is a need to replace certain elements during the installation or service life, since there is not easy finding the same products needed on the market. Marketing to advertise for BIPV products and solutions is also missing, making it difficult for actors in the building sector to find appropriate solutions with BIPV in a building project. Software tools also need the implementation of BIPV products so that it can be incorporated in the beginning of the planning process [44].

2.7.6 Support mechanisms in Norway

Enova support

Enova support is a support scheme for private households where the intention is to create initiatives to improve the energy used in buildings. The amount of support depends on the size of the facility. A fixed sum of 10,000NOK will be given for the actual installation of the plant, and the rest of the supports depend on the capacity. As of today, one get 1,250NOK per kW installed power up to 15 kW. The maximum support will be 28,750NOK. The fixed part of the support will be reduced from 10,000 to 7,500NOK on 1 July 2021. The variable part per installed effect will be the same [46].

"Plusskundeordningen"

"Plusskundeordningen" is for end users of electricity who want to produce and consume their own energy. A "Plusskunde" produces its own electricity and will use this to partially cover its own consumption. If production is less than needed, one must buy electricity from the power supplier. The prosumers do not need to pay any grid-fees for the PV electricity they consume. If production is more than one's own consumption, the excess PV energy is sent into the grid. The price for the excess PV energy is usually the spot price. An important prerequisite for being able to call oneself a ”Plusskunde” is that one can not feed more than 100 kW into the grid at any time [47].

2.7.7 Costs

The end user cost of the BIPV system includes planning/engineering, BIPV modules, transport of the components, electrical parts, anchoring and mounting parts. The costs might become higher depending on the complexity of the project. There is a big difference between the cost of conventional PV modules and custom made modules. The custom made is definitely more expensive, but one get certain advantages like better aesthetically integration and the functionalities needed to get the roof tight. Conventional modules are seen as more competitive and they have a relatively low cost. From Figure 2.11, it is evident that a conventional roofing system in combination with BAPV might lead to drastically higher cost than for a BIPV system [42].

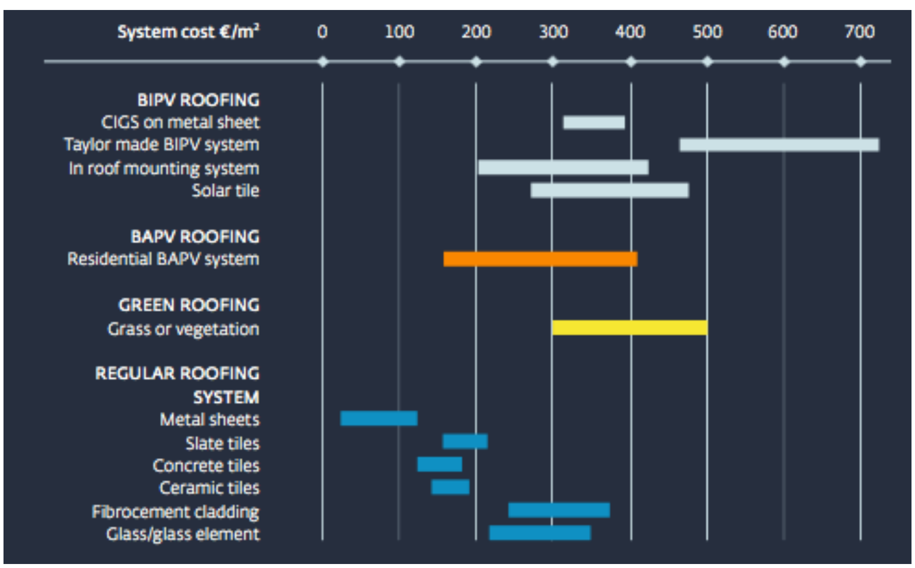

Figure 2.11: *End-user cost of conventional and PV materials for roof [42].*

When looking at the system cost for facades in Figure 2.12, there is a wider range of costs. A reason for this is that every project is project specific. The project's complexity matters, and also the size of the installation.The size, thickness and type of modules are different depending on the project and the location of the building will play a significant role [42].

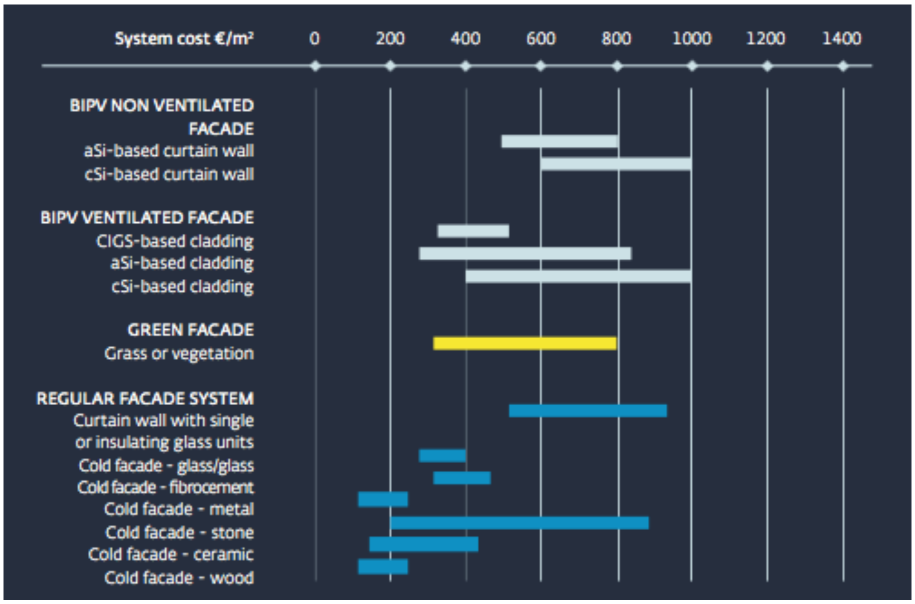

Figure 2.12: *End-user cost of conventional and PV materials for facade [42].*

2.7.8 Technical challenges

The complexity of designing a BIPV system occurs due to multidisciplinary. It is necessary to reach an agreement between economic considerations, aesthetics, requirements for building regulation and between optimal operating conditions for photovoltaic systems. Before and after the completion of the project, one must pay attention to the planning processes and assignment of responsibilities. Cooperation between several industries is necessary when it comes to planning, engineering and implementation of a building-integrated system [48].

Shading

BIPV is more vulnerable to shading because the modules must be laid according to the building's construction. For the rehabilitation of buildings, one only have the option of laying it the way the building has already been constructed, while for new buildings one can design this to make the most of the sunlight. A major disadvantage of the facade in particular is that the shading can be changed due to new buildings or a different user behavior [48].

Shading is a challenge for the modules depending on the local climate which can be due to dust, snow or from objects nearby such as trees or a building construction. Any shading will decrease the solar transmission through the PV modules resulting in a decreased power output. Particles deposited on the modules are various in size and different locations will have different shading depending on the climate. Some locations will suffer more from rain and salts, while others from windblown dirt or atmospheric pollutants from fossil fuels. The orientation of the modules and wind direction will have an impact on dust deposition. The shading effect can be reduced significantly by heavy rainfall, wind or self-cleaning methods [40]. BIPV modules are more exposed to shading than ground-mounted power plants [49].

Degradation at increased temperature

When considering the incoming solar irradiation, 15-20% of it will be converted into electricity while the rest of it will be dissipated as heat. This will indeed cause heating of the solar modules. The temperature impact on the first generation solar cell is the most affected regarding a temperature increase [40].

Thermal regulation

Passive or active heat removal methods can be used for dissipation of heat from the modules in order to improve the PV performance. Passive methods rely on conduction, convection and radiation while active methods use pumps or fans for cooling. When mounting a PV system there should be an air gap between the modules and the facade allowing for ventilation. If there is no such gap between the modules and the building skin it will cause unwanted heat into the building space resulting in decreased efficiency. Air cooling is the most common method used for BIPV systems [40].

Module dimensions and designs

BIPV modules can be customized in sizes, designs and formats to meet specific architectural design. When not dealing with standardized modules, there might be a challenge testing the modules performances, including mechanical, electrical and optical properties. Solar simulators used for testing the modules might not fit customized modules, nor rollable, flexible thin-film modules for instance. These modules need to be tested in the outdoor environment, which might cause more measurement errors due to being exposed to a less controllable environmental condition. BIPV module standardization, testing and certification needs more design options and flexibility in order to solve this challenge [49].

Fire safety

The risk of fire is an important factor when considering PV systems in general. The report Laukamp et al states that BIPV systems have a 20 times higher risk of fire incident than BAPV [50]. Junction boxes and inverters are considered the main causes of fire in these systems. Even though BIPV has a drastically higher risk of fire than BAPV, there seems to be a lack of further studies on this topic. Some suggestions for further research should include testing methods and procedures, monitoring during operating conditions and a clear regulatory framework. Clearer requirements for modules mounted vertically on the facade are also needed. The conclusion is therefore a need for modifications on standards regarding fire safety for BIPV systems [49].

There are recognizable challenges in connection with safety and energy-efficient buildings. One fire study specifically highlighted that regulations cannot keep pace with the new solutions that are continually being formulated [51]. With an increasing number of solar cell installations, the number of fires has also increased. However, fires in photovoltaic systems are considered a rare occurrence [51]. The fire at ASKO, where the building had solar cells on the roof triggered the debate about solar cells and fire safety in Norway. The fire actually started inside the building and then spread to the roof where the photovoltaic system was located [52].

According to a supplier of solar cells, there should be no worries provided the facility has been efficiently planned and good components have been used by qualified professionals. A proper inspection at the end of the installation process is also very important [53]. There is an increasing number of building integrated photovoltaics, which may introduce more challenges for fire safety in buildings. BIPV is a part of the building, as well as being an electrical component [54].

Tekna arranged a webinar on fire safety and photovoltaic systems in 2020. This included a presentation from the fire service with their views on this topic. The biggest challenge and danger confronting them is the high voltage generated during a fire in a building with a solar cell system. Exposure to excessive heat can cause BIPV on a facade and the aluminium fastening systems to collapse. It is therefore extremely important to label a photovoltaic system. This should preferably be at the main entrance. It is advantageous for the fire service to have as much relevant and correct information available as possible during the operation. A drawing or overview of the location of both systems, inverters and a switch that can turn off power from inverters are advisable [55].

A starting point for all firefighters must be the knowledge that where there are solar panels there is always voltage. Extinguishing a system with solar cells means extinguishing a facility that has voltage. This knowledge is beginning to be comprehended [52]. Italy had over 800 fires in 2012 in buildings with solar cells, and it may seem that the development happened a bit too fast at the same time as there were many unprofessional actors that led to these problems. Up to now the solar cell industry in Norway has experienced nine fires, but after NEK 400:2018 was released, people realize solar cells become an electrical system and the installation must be done by an electrical company. This hopefully makes Norway avoid the problems of lack of competence that they experienced in Italy [56].

Some attempts have been made to see if fire spreads faster behind the gap located in the back of the modules. This seems to be confirmed, and if the air gap is very small, it might seem like a drastically faster flame is produced. Some firefighters think that it is dangerous to flush water on solar cells. Research shows that it should be safe to flush water on the photovoltaic system as long Norwegian water is used and a distance of 1 meter is kept if having scattered flush and a distance of 5 meters if having collected flush. This is based on tests where flush water is used on live components and look at the current passage between the water jet. An important finding in the study was that if standing in a mud puddle and extinguishing the fire, one can be electrocuted, so this is necessary information for firefighters [57].

3 Methodology

This chapter will present a description of the research approach and argumentation for the choice of method. Then an evaluation of how data were collected during the interviews will be presented.

3.1 Choice of methodological approach

In social science methodology, a distinction is made between quantitative and qualitative methods. Quantitative data includes information that is encoded into numbers, while qualitative data is information that is conveyed in the form of words [58]. The problem statement is decisive for which method is chosen. The problem statement of this thesis is exploratory, which means that it intends to deepen peoples' lesser known knowledge [58].

In this thesis the method used was a qualitative research method. This method is used to describe and examine peoples' opinions and experiences [59]. Data collection for the thesis will be through literature review and interviews to obtain a better understanding of the technical challenges, soft challenges and standards regarding BIPV. In order to get a better insight within the BIPV market in Norway, it seems more applicable talking to people rather than collecting numbers. A qualitative research will give an overview that can help map the informant's experiences and opinions as well as elaborate on the topic and bring out nuances. Another advantage is that informants provide guidance for which information they find relevant.

In addition to a qualitative research method used in this thesis, a small quantitative study was done in order to highlight important findings from the qualitative study. The survey was sent out after finishing the qualitative study and provided data that were compared with information collected from the informant interviews.

3.2 Case study: use of BIPV in the Norwegian context

In this qualitative research a case study has been used. A case study focuses on a phenomenon, in this case the usage of BIPV and combines an understanding and exploration of complex issues.

Studies used to describe something will focus on describing similarities and differences, while studies used to explain something need to consider why there are similarities and differences. Explorative studies seek to find new knowledge on a topic where there is little advanced knowledge [60]. The problem statement formulated in this work explores challenges with BIPV in Norway and how to ensure market access to the solar energy market. The purpose of this study can be described as explorative. Explanatory questions will be answered using the words “how”, “why” and “which”. These types of questions seem promising when analysing current and future events and can be done using documents, observations, interviews and objects [60].

The use of case study as a research strategy has been criticised. One relevant criticism is the lack of accuracy due to unorganised work and openness to more than one interpretation of the findings. Another criticism has been that case studies are not adequate enough in order to provide scientific generalisations. A case study is supposed to advise with analytic generalisation, not statistical generalisations [60].

For this project, many different actors in the solar sector were interviewed rather than choosing a specific project/infrastructure. As the research question emphasises, the goal is to find out what makes BIPV challenging in Norway, and how standards can help to make it easier to offer good BIPV solutions. The reasoning is that by talking to many actors involved in the technology, a better impression of the current situation in Norway will be obtained, together with what has to be done for larger scale implementation of this specific technology. The project has a limited time frame and its scope restricted to between 2-7 interviews within each category of informants.

3.3 Data collection

This section explains the methodology used to answer the research questions. This study is based on document analysis and personal interviews.

3.3.1 Document analysis

The background for the master thesis is the interest in renewable energy development, looking into solar energy and specifically the BIPV technology for Norway. Research by reading news articles, research papers and online websites was undertaken to obtain more information about today's situation regarding this technology. Semi-structured interviews were used to answer the research questions of the thesis and were the primary source of data used for obtaining the results. The method of data collection is related to the use of secondary data, i.e. data that are not collected by the researcher himself [59]. It is said that most research projects require a combination of primary and secondary data in order to be able to answer the research questions in the study [59]. Therefore a combination was chosen to supplement and compare with research in this field.

3.3.2 Semi-structured Interview

A major part of the thesis includes semi-structured interviews with various persons with key expertise on the topic. People with different backgrounds and connections related to the topic were interviewed to obtain an overall picture. This included interviews with different actors in the photovoltaic industry as experts, suppliers/installers, architects and builders within the technology. An interview with a company from Estonia was also included in order to compare their situation to Norway. When using a semi-structured interview guide, the questions can be customized based on the pre-planned questions. This opens up for deeper discussions and follow-up questions if necessary. The respondent gets the chance to supply the information he/she finds important to the research [58]. The administration of the interviews and the interpretation of the collected data are time-consuming and resource intensive. The content will provide information that has to be analysed thoroughly, and there is also a possibility of accessing further information if something seems unclear.

3.3.3 Interview guide

A semi-structured interview was used due to the flexibility this gives in choosing the direction of the interview. Before the interviews, an interview guide was compiled to address the important research questions. The reason behind this was to examine the informant's knowledge of the research topic. One interview guide was made for Norwegian informants, which included customized follow-up questions based on the informants background (Appendix A and B). A different interview guide was used for the Estonian company (Appendix C). This gave a good basis for further interpretation.

3.3.4 Selection size and strategy

Obtaining a large amount of information from a limited number of informants is what characterizes a qualitative method [58]. How many informants are needed depends on the problem statement, and in this work the number was limited to 20 due to the time limit for the task. The goal was to get some representatives from each category. In order to obtain an overview of the situation regarding the usage of BIPV, several actors involved in a BIPV project were contacted. This included talking to 7 experts, 6 suppliers/installers, 2 architects, 3 builders and 2 manufacturers.

In qualitative surveys, it is important that the informants chosen will be able to express themselves reflectively on the topic [58]. To find good contacts with knowledge of the topic, research was done to assess their experience within BIPV. An email with information about the thesis was sent to relevant contacts. Some people referred the email further to colleagues and contacts in the sector that they knew had more experience on the topic.

3.3.5 Completion of interviews

The interviews were conducted over a period of six weeks. This gave time to evaluate and transcribe each interview continuously, which was very convenient. The majority of the interviews were conducted using Teams and Google Meet, due to the Covid-19 situation. All the digital interviews were conducted with a camera on, in order to be able to look at social and emotional aspects during the interview situation that could be of importance to the analysis.

One day before the interview, the informants were sent some information about the topic of the master's thesis as well as a statement of consent to be able to participate. The informants' responses should be based on their reflections and thoughts without having planned an answer in advance, so they did not get the interview guide beforehand. The informants were encountered as informative, and were willing to share their own experiences and views. The interviews were characterized by trust and openness.

Audio recordings were used during the interviews. This allowed for active listening, and asking relevant follow-up questions. The same interview guide was used in each interview, except for different follow-up questions, which made the comparison and analysis work easier. All interviews were transcribed afterwards. Transcription means to transform the oral interview conversation into a written text [58]. In order to make the interviews available for analysis, this is an important procedure. The transcription has to be easily read, and contains the most important aspects of the informant's response. Emotional expressions are therefore not taken into consideration.

3.4 Evaluation of data collection

The method chapter will end with an evaluation of the data collection for the study. Due to the covid-19 situation, pros and cons of digital interviews in the research will be discussed. To assess the quality of empirical research, the concepts of reliability, validity and generalizability are key concepts. These concepts are closely linked to quantitative measurement, and this is one reason why these concepts have been discussed for use in qualitative research methods. Due to this, Thagaard [61] prefers the concepts of credibility, confirmability and transferability rather than reliability, validity and generalizability. Credibility is about the research being carried out in a trustworthy way. Confirmability is linked to the quality of the interpretations made, while transferability is about the extent to which the project's interpretations have relevance and context in other situations [61]. Finally, ethical reflections on the study's data collection and privacy will be presented.

3.4.1 Pros and cons with digital interviews

There are several advantages and disadvantages of using digital software for qualitative interviews. There are several major advantages of digital interviews. Time and money can be saved. There are no geographical restrictions. Interviews can be conducted in a safe and private place. Nervousness experienced in physical personal interviews can be reduced. The digital softwares used for the interviews, both Microsoft Teams and Google Meet also have a useful feature that automatically creates a meeting time in the calendar of the informants after agreeing to participate in the interview [62].

Digital interviews are dependent on a good internet connection and therefore have a negative aspect if the interview stops due to poor connection. This can affect both the sound and quality of the interview, even though it doesn't necessarily lead to the interview being terminated. This is very negative because one wants to listen clearly to the informant's personal opinions and word choice in a qualitative interview. Background noise can also affect the interview and transcription, but this is something that can affect physical interviews as well. Another disadvantage is that only the face and the upper part of the body can be seen, which hinders the ability to observe body language and attitudes [62].

3.4.2 Credibility

Credibility involves how the research has been completed and whether it has happened in a trustworthy manner [61]. A reflection has to be made on the context for the collection of data, and how the relationship with the informant can influence the information received during the interviews. Whether the relationship with the informants has been characterized by openness and how the research process has developed will be examined.

The informants were perceived as engaged and willing to share their experiences, feelings and views. Credibility was ensured through an interview guide that did not contain leading questions, but rather opened up for the informants to clarify their views on the topics.

3.4.3 Confirmability

The term confirmability refers to the extent to which the results of a qualitative study can be confirmed by other researchers [58]. The confirmability related to the study is assessed in relation to the problem statement and the connection between the choice of method and design. These choices may have had an impact on the presentation of the interview data.

Confirmability has to ensure that the results of the research are based on what has been completed, and not on the researcher's informative attitudes. An important element to ensure confirmability is that the informants recognize themselves in the interpretations, which is claimed to have been achieved by using transcripts of the interviews to analyze data. Interpretations made in the study should also be supported by other researchers. For this work, reading previous research has given an understanding of what is in the literature already. The study identifies a gap in the existing research will provide an insight into the challenges and standards of BIPV in Norway and what is needed for the technology to become more widespread.

3.4.4 Transferability

Qualitative studies deal with transfer of knowledge, rather than generalization. Generalization is more used in quantitative studies when analyzing statistics. Whether the study succeeds in establishing concepts, descriptions, explanations and interpretations that are useful not only in the area being studied deals with transfer of knowledge [58]. Through a description of the research questions, findings and analysis, the reader has the opportunity to understand whether the thesis is transferable in a different context.

3.4.5 Ethical reflections

Throughout the entire research process, the ethics of research have been considered carefully. Ethics have been taken into consideration from planning to collection process [63]. The participants should be informed about their rights during the research process [63]. Before starting the interview process, an application was sent to the Norwegian Centre for Research

Data (NSD) to ensure that the research has legal access to necessary personal data. All projects that involve the processing of personal data must be reported here [64]. The day before the interview, the informants received an email including an information letter and a statement of consent. Information that no personal details will be included and withdrawal at any stage from the process were clarified. This is done in order to protect the individuals. The informants are referred to as their occupation (experts, suppliers/installers, architects and builders).

After conducting the interviews, the recordings and transcripts were saved and coded so that the informants' identities were not recognisable. It is also important that the data should not be kept longer than needed for the research [63]. The informants were informed that all the identifying personal information will be deleted when the project is completed.

4 Results

This chapter includes a representation of the findings. Allowing for the extensive amount of information obtained during the interviews, the answers will be categorized into technical challenges, soft challenges and standards as shown in Figure 4.1. The section about technical challenges will only include answers from the experts and the suppliers/installers. The other categories will be further divided into experts, suppliers/installers, architects and builders in order to get a better overview of the different groups of informants. An overview of the situation regarding some of Norway's neighboring countries will also be presented in a separate section. An in-depth interview with a company from Estonia will also be presented comparing their situation with Norway. Document analysis has also been included in the discussion section to shed light on the answers received. This provided a basis for a more accurate analysis.

Figure 4.1: *Main categories findings.*

The results including references to the tables in this chapter also include the quotes from the informants. The sentences containing these quotes are referred to as "s" and are marked in numeric order from one.

4.1 Technical challenges

In order to figure out more about challenges with BIPV, it was essential to explore further the technical challenges with this technology. It was beneficial to conduct an interview with the experts and the suppliers/installers on this topic due to their abundant knowledge.

4.1.1 Experts

The experts involved in the interviews are major actors in the solar cell industry. These have given a better understanding and insight of the market situation for BIPV, and what challenges are present.

Fire safety
When asked which technical challenges faced BIPV, fire safety was a common answer. Lack of studies on fire safety and BIPV has been mentioned by the majority of the actors. This is something that is very important to be aware of in the different situations that may arise (Table 4.1, s.1, 2).

Shading
Several informants have stated shadowing as a problem for BIPV and this must be carefully considered. Newly erected buildings after the system is installed will impact the shading and this might be challenging to deal with (Table 4.1, s.3).

Inverters
The use of invertes is something the informants have discussed as a critical issue. Some inverters seem to be more effective to use than others when it comes to BIPV, and it is important to be aware of the different technologies that could be used (Table 4.1, s.4).

Replace and repair modules
One of the informants mentioned module failure and had a clear opinion of this problem. It seems to be more difficult on a facade due to the modules being vertical (Table 4.1, s.5). Unpredictable events can also occur that can make this even more difficult to handle (Table 4.1, s.6).

Simulation
The availability of simulation softwares and a need for further improvements in this area were examined. Several informants had the same opinion about the difficulty and time-consuming process when carrying out the simulations (Table 4.1, s.7, 8).

Thermal regulation
As some informants have mentioned, thermal regulation might be a challenge for BIPV modules. When BIPV modules are dressed into the building one have to be careful that adequate ventilation is produced at the rear edge of the module (Table 4.1, s.9). The advantages and disadvantages with ventilation when using BIPV where highlighted by one informant (Table 4.1, s.10).

Testing the performance
One of the informants mentioned the testing of performance as a challenge with the BIPV modules. This job seems to be easier when considering standardized BAPV modules (Table 4.1, s.11, 12)

Monitoring the performance
When asking about monitoring of BIPV system, a feedback was given that it can be difficult to monitor these systems depending on the complexity of the project. An inverter could be used to detect large problems, but a thermal imaging cameras will be better to detect smaller failures that might occur (Table 4.1, s.13, 14, 15, 16)

Responsibility
BIPV falls between two areas of expertise which might lead to some problems regarding responsibility if something goes wrong. One of the informants specified that this can make the projects technically challenging (Table 4.1, s.17).

4.1.2 Suppliers/installers

The suppliers/installers have made an important contribution to the thesis by relating their experiences and knowledge about this technology. The suppliers contacted are also involved in the installation part of the facility.

Fire safety

It is important to plan, design and install according to NEK 400 (Table 4.1, s.18). The informants also wanted to highlight the difference in involvement when comparing large projects and installations on private buildings (Table 4.1, s.19). Despite these differences, any building containing a solar cell facility should always be distinctly marked (Table 4.1, s.20).

Replace and repair modules

As the informants emphasise, BIPV modules are more challenging when considering the customized modules. It would be practical to order one or two extra customized modules to make replacement and repair of modules easier (Table 4.1, s.21, 22).

Simulation

Many informants emphasise the need of more simulation tools specifically for BIPV. When simulating BIPV modules the tools in use today might not give very accurate results. It is also shown from the informants that this type of simulation is more comprehensive (Table 4.1, s.23).

Thermal regulation

Several informants have mentioned ventilation behind BIPV modules as an important aspect to consider. It is important with adequate ventilation at the rear edge of the solar modules because this will improve the overall efficiency (Table 4.1, s.24).

Table 4.1 Technical challenges
Experts
Fire safety
1) ”Fire safety is extremely important” (Expert 5)
2) “There are currently few studies on integrated solar modules and fire safety” (Expert 7)
Shading
3) ”BIPV is more challenging when it comes to shading, so planning an efficient string design is very important” (Expert 6)
Inverters
4) “Inverters are a problem and BIPV will be easier with module level power electronics, but problems arise if you need to replace every single small power electronic box which is on the backside of the module in a facade, for example” (Expert 6)
Replace and repair modules
5) “It is complicated to replace and repair BIPV modules. This is due to the fact that most of the BIPV modules are custom made for a specific project" (Expert 2)
6) "A company that produced customized modules became bankrupt, and there were many questions on how to handle a potential incident after this" (Expert 7)
Simulation
7)“It is a mess to simulate a BIPV project because everything is based on the standard solar energy technology” (Expert 6)
8)"There are no dedicated softwares or tools for BIPV modules, but that would be very useful in the future" (Expert 7)
Thermal regulation
9)“Very often when the modules are integrated you don't have any airflow of the backside of the module” (Expert 7)
10) “You could ventilate the facade but then you would lose thermal insulation of the building, but you would gain in the energy production. So you always have to do iterations and there is always this kind of iteration process when we plan BIPV projects” (Expert 6)
Testing the performance
11) "BIPV has a very high cost for testing the modules. To be able to make a data sheet of the modules you need to send it to a proper testing lab/facility, and that costs” (Expert 7)
12) "It is difficult to test the modules in solar simulators because they are custom made" (Expert 2)
Monitoring the performance
13) "Monitoring of a PV facility is often done with a switch inverter. A thermal imaging camera has to be used when detecting smaller problems” (Expert 7)
14) "Monitoring on a facade is complicated because the temperature sensor will be impacted by the inside temperature" (Expert 6)
15) "Monitoring could be challenging when dealing with a complex facility" (Expert 5)
16) "Often we can just accept that a powerplant is less monitored than other parts of the plant" (Expert 6)

Table 4.1: *Summary quotes technical challenges.*

Who is responsible?
17) “When we add BIPV it is between two areas of expertise, so we need to make special agreements if something is wrong with the system” (Expert 6)
Suppliers/installers
Fire safety
18) “There are many who are sceptical in relation to fire safety, and since it is an electrical installation it is important to plan, design and install according to NEK 400" (Supplier/installer 4)
19) "Dialogue with the fire service is important in large projects, while private buildings don't have the same criteria" (Supplier/installer 2)
20) "A photovoltaic system always has to be clearly marked" (Supplier/installer 4)
Replace and repair modules
21) If you are accidentally destroying a customized BIPV module then this must be ordered from the supplier, and you might have 8 weeks delivery time, so we have been more careful with the special products” (Supplier/installer 2)
22) "Where possible, one should order one or two extra customized modules in case something break. This will make repair and replacement much easier" (supplier/installer 4)
Simulation
23) "It would have been great if there was a program that worked better for simulating BIPV" (Supplier/installer 4)
Thermal regulation
24) "You have to be careful that you have adequate ventilation at the rear edge of the solar module. Solar modules work better when the temperature is low” (Supplier/installer 5)

Table 4.1: *Summary quotes technical challenges continued.*

4.2 Soft challenges

4.2.1 Experts

Challenges

In order to get a better understanding of the challenges with the BIPV technology in Norway today, a question was asked about the experts’ thoughts on the main challenges with this specific technology. The majority of the informants specified that there is a need for more competence for everyone. This applies to manufacturers, suppliers, installers, architects, builders and customers (Table 4.2, s.1). One informant points out lack of knowledge and conservatism important to be taken into account. The construction industry has been seen as conservative, favoring to do things the way they always have. This is also an important factor that may have slowed down the implementation of solar cells, and specifically BIPV (Table 4.2, s.2, 3). Awareness of the benefits of BIPV should be in focus in shaping the future of the industry.

Another challenge that the informants touch upon that affects people in this sector are challenges due to more multidisciplinary compared to a regular BAPV installation (Table 4.2, s.4). There is apparently a need for more cooperation between all actors to facilitate planning and installation of BIPV.

Politics

On being asked what is necessary for further widespread development of this technology, one informant mentioned the importance of market push and market pull (Table 4.2, s.5). This will be particularly important for a technology like BIPV which is a niche technology. It is important that politicians get more involved, while at the same time having a market that is competitive.

Most of the informants mentioned that incentives like Enova support can play an important role in accelerating the growth of solar cells, and it is perhaps especially important for BIPV, which is currently considered as a slightly more expensive technology (Table 4.2, s.6). One informant discussed the implications of Enova cutting down their support from July 2021 which might affect the implementation of solar cells (Table 4.2, s.7).

Costs

It was necessary to ask their thoughts and experiences regarding the costs for BIPV (Table 4.2, s.8, 9). One of the informants specified that it is important to think that when choosing BIPV, conventional building materials are actually replaced. This can lead to eventual cost savings depending on the BIPV technology chosen (Table 4.2, s.10).

4.2.2 Suppliers/installers

Experiences

Experiences working with BIPV gave various results. Some companies find it more difficult than others, based on the companies background (Table 4.2, s.11, 12, 13). Other informants mentioned that it was not challenging for them due to the companies historical background as roofers and facade entrepreneurs (Table 4.2, s.14, 15). One informant touched upon the potential for introducing BIPV while others though it had a limited potential since BIPV is mostly used when renovating or building new house (Table 4.2, s.16).

Challenges

A question was asked about challenges the informants faced during a BIPV project. This included challenges before, during and after the project was completed. This gave a better understanding of the challenges in this technology that might not be so prominent in a regular PV project. During the planning of the project, all the informants specified that the multidisciplinary is very important for BIPV. There are more people involved from different sectors that need to cooperate and plan this as efficiently as possible (Table 4.2, s.17, 18, 19, 20). One informant specifies that it requires much more accuracy and precision. Most of the informants agree that it is more advanced with BIPV on the facade than on the roof (Table 4.2, s.21, 22, 23). Some informants mentioned the difficulty with documentation in the beginning. The informants also agree that an inspection with the firefighters is important to make them more acquainted with the facility in large projects in case of an incident (Table 4.2, s.24, 25).

Politics

Politics were also mentioned by the majority of the informants when asked about what is needed for further development. There seems to be an agreement between the group of informants that this is a potential barrier to making the technology more widespread (Table 4.2, s.26). Several informants touched upon the fact that the solar installation should not be bigger than what the building uses itself. It might be a drawback for commercial buildings as they usually have a greater area in which to put the solar cells (Table 4.2, s.27). Some of the informants consider support schemes from the government as a key factor for solar cells in general. As one of the informant touched upon, batteries for electric vehicles have had a major growth during the past year due to incentives from the government. This amount of support has not been available yet for solar cells (Table 4.2, s.28). One of the informants mention how difficult it was to get approval from the Planning and Building authorities when considering solar cells on protected buildings (Table 4.2, s.29).

Costs
There are different opinions on how costs will influence the installations of BIPV facilities. Some informants definitely point out that the higher costs are a barrier, and they agree that lower costs and more subsidies would help the development (Table 4.2, s.30). Other informants mention how BIPV does not really need any support and is considered an investment. These informants think that rising awareness of the technology itself is more important than just the costs of the technology (Table 4.2, s.31).

4.2.3 Architects

Architects have an important task in recognizing the benefits and potential of applications for BIPV. Their role as a consultant and idea supplier is important in order to present this to the construction developer.

Experiences
A question about the architects' experiences working with BIPV was asked. The informants emphasize that it is normal that people might be sceptical about having solar cells on the buildings, and especially when considering having it on the facade (Table 4.2, s.32, 33). One informant emphasizes the importance of more competence regarding BIPV and the need to simplify work with this technology (Table 4.2, s.34).

Challenges
The informants touched upon the challenge of the conservatism found in the construction industry (Table 4.2, s.35, 36). Another informant specified how difficult it was to find the right products for the BIPV project. A limited supply of products in Norway and the restrictions imposed by Norway on some international products make this a definitive challenge (Table 4.2, s.37).

Politics
The architects also mentioned politics when asked about what is needed for further development. One of the informants touched upon a very important statement about the need to change the way the buildings will be built in the future (Table 4.2, s.38). The Planning and Building authorities are not seen as a driving force for solar cells in general. The informants

had several examples where projects with solar cells had been rejected due to aesthetics (Table 4.2, s.39, 40). One informant talked about how slow running the development with more energy-efficient buildings has been in Norway compared to other countries (Table 4.2, s.41).

Costs
The costs of BIPV systems was not seen as an obstacle by the architects. As they tried to emphasize, the costs are more affected by the people who have to deal with the payments (Table 4.2, s.42, 43). Since cost are always carefully considered in projects with BIPV, one informant specified the importance of including BIPV in the planning from the start because projects become very expensive if BIPV is assessed after projects have been started (Table 4.2, s.44).

4.2.4 Builders

A builder is the owner of the property on which work is to be carried out. Furthermore, builders use contractors, including electricians, masons and carpenters to carry out construction work.

Experiences
The informants interviewed have high ambitions to contribute solving climate change. If they are allowed to use solar cells that prove to be cost-efficient they will use this technology (Table 4.2, s.45). One informant who has been participating in several projects with high energy ambitions stated that there is no chance of realizing the Paris agreement without looking at rebuilding of existing buildings. He further pointed out that as long as buildings are torn down before starting the new project, there is no way the release of huge emissions can be avoided (Table 4.2, s.46).

Challenges
The topic of challenges was also asked here in order to compare the different categories and what they emphasized as the most difficult parts. One informant specified how the architects have to become more familiar with the BIPV technology in order to make the right choices that will positively affect energy production and aesthetics (Table 4.2, s.47,

48, 49, 50). These findings indicate that market awareness is important in order to be able to use and utilize BIPV technology in the best possible way.

Politics

When asking about what is needed for further development, the informants touched upon the same arguments as the other categories. One of the informants specified the need to help the politicians to achieve their environmental goals, even though there is no law as yet to enforce the building sector to build environmental architecture to the extent they do today (Table 4.2, s.51). The planning and Building authorities attitudes towards solar energy is something the informants think is important to highlight (Table 4.2, s.52, 53). One informant said that they were required to rebuild their solar energy project on a commercial building because the Planning and Building authorities thought that the aesthetics were not sufficiently taken into account.

Costs

As one of the informants wanted to highlight, as long as people in the sector get used to new ways of building, then it is not that costly anymore. The informant wanted to emphasize that a lot of research and effort was needed in their first BIPV project. This research and effort will be reduced as they become involved in following projects (Table 4.2, s.54). Some informants also mentioned that BIPV can become quite expensive both depending on the project and how it has been included in the planning process (Table 4.2, s.55, 56). One builder mentions how much responsibility they have for everything to succeed and this is obviously a good reason why they will always have to consider the costs associated with the projects (Table 4.2, s.57). The informant gave a good example of what it would be like in an ideal world where technologies would be more competitive and all actors would be more comfortable with costly projects (Table 4.2, s.58).

Table 4.2 Soft challenges
Experts
Challenges
1) “Lack of competence, but there is also culture and conservatism" (Expert 1)
2) “There is a big lack of awareness when it comes to what you can do and what you can not do” (Expert 7)
3) "Lack of knowledge seems to be particularly for private individuals that are not aware of the different solutions that exist" (Supplier/installer 5)
4) “It is complicated that you combine two traditions, one which is electrical alone, and then there is the building” (Expert 2)
Politics
5) “There must be market push and market pull, there must be political push at the same time as you have a market that is also attractive or competitive. Because if you only have one, it is a bit difficult to have the development you want, or get where you need to go” (Expert 5)
6) "Enova support for BIPV would be welcome" (Expert 3)
7) “Norway thinks the market is mature long before other countries do, so Enova withdraws and says that now we think the market can go by itself" (Expert 4)
Costs
8) “BIPV is more expensive compared to a regular PV installation” (Expert 4)
9) "BIPV is mostly used in energy-efficient buildings with high energy ambitions due to the costs" (Expert 5)
10) "With BIPV you replace the facade and roofing material and it is calculated at price per square meter, and then the cost level is actually quite reasonable" (Expert 1)
Suppliers/installers
Experiences
11) “It has been difficult at times” (Supplier/installer 2)
12) ”What I want to emphasize the most is the level of prestige, requiring more skills from the installers” (Supplier/installer 2)
13) “For the time being, it is a new way of working. We had to learn a lot more building technology” (Supplier/installer 4)
14) “It is not something that is challenging for us, we have been working with roofs for many years, so we have the knowledge on getting the roof tight” (Supplier/installer 6)
15) "Our historical background as facade contractors makes us very well equipped to seal a building, which will make it easier to implement BIPV" (Supplier/installer 1)
16) "You could say that there is a limited potential for introducing BIPV, but there are still customers with a relatively new roof that choose BIPV due to aesthetics" (Supplier/installer 2)
Challenges
17) ”There is a lot of multidisciplinary and it must be coordinated. Especially if you work with facade cladding where everything has to fit with windows and seams and everything else on the building, it must be coordinated to a much greater extent with others” (Supplier/installer 1)
18) ”When working on a BIPV project, you must first go on an inspection, and take measurements of the roof. You do not necessarily need to do this when planning a BAPV installation. And when you start working again, the first thing you should do is double-check all the measurements after the roof tile has been removed” (Supplier/installer 2)
19) "Design and start-up take time to try to avoid errors that can delay the project” (Supplier/installer 4)

Table 4.2: *Summary quotes soft challenges.*

20) "Some times we are responsible for part of the construction technology in a BIPV project, while other times we come into play after the solution is decided and we have less responsibility here" (Supplier/installer 4)
21) "There are completely different requirements for accuracy because everything has to fit into the building. It becomes more visible if something is not completely accurate" (Supplier/installer 1)
22) "Solar cells are tempered glass, and you can get customized glass panels that will fit exactly in that corner of that building, but you cannot customize it on site. It must be produced to the millimetre and fit to the millimetre, so in that sense the solar panel is an inflexible building material" (Supplier/installer 2)
23) "The building is not necessarily completely straight, so you may have deviations on the building. Your modules are the size you have had them produced in, so you have to be able to solve this" (Supplier/installer 4)
24) "There have been a lot of mistakes in the documentation of BIPV. Many installers have experienced deviation when the facility was checked. Very often it was related to the documentation and not necessarily the electrical safety of the plant" (Supplier/installer 1)
25) "The fire department should be allowed to join early in the process and be allowed to make their views known, and make objections if they have them. It is also important to make them familiar with the facility and invite them for an inspection after completion of installation" (Supplier/installer 4)
Politics
26) "Support schemes and having a plan from the authorities about what they really think about the green shift is needed for further development, because it has been a bit diffuse for solar cells" (Supplier/installer 5)
27) "There are too many restrictions from the authorities regarding regulations, for instance when it comes to the sale of electricity. This has to change" (Supplier/installer 3)
28) "There are very few incentives to choose solar cells in Norway. All the money that Enova has, or much of what Enova has, goes to batteries. When it comes to solar cells, the support is almost zero. When they are not prompted to support more in the phase we are now, then they choose not to" (Supplier/installer 3)
29) "It has been difficult to implement solar cells on protected buildings in Norway" (Supplier/installer 6)
Costs
30) "Price is an obstacle for BIPV, and it is perhaps a reason why it has not been used more than it is until now. But we see that the price of the cells themselves will be much cheaper" (Supplier/installer 4)
31) "It is clear that it is more expensive with a solar cell facade or integrated solar cells on the roof, but this also gives something back in the form of getting electricity production" (Supplier/installer 2)
Architects
Experiences
32) "I think people are a bit scared to have it on the facade for the expression" (Architect 1)
33) "People are not aware of the different solutions that exist. BIPV modules could be custom made, and different colours and shapes could be chosen which makes this technology more attractive" (Architect 2)
34) "Subsidies are super important, and so are courses, perhaps in that order" (Architect 1)
Challenges
35) "The construction industry is conservative, and they have to deal with risk management and finances. So they will keep their methods that they know work for as long as they can before they are somehow forced into something new" (Architect 1)
36) "Builders should get more expertise so that they know what benefits exist with BIPV" (Architect 2)
37) "There are some obstacles since Norway is not part of the European Union" (Architect 2)
Politics
38) "The authorities must be willing to accept that our buildings look a bit different when we are to produce more renewable energy, it is a consequence of that investment and it must also be included" (Architect 2)

Table 4.2: *Summary quotes soft challenges continued.*

39) "I get a bit tired of Planning and Building authorities being taste police, putting themselves above the rules and the environmental goals that the projects have" (Architect 1)
40) "It is a big obstacle if the Planning and Building authorities say no to solar cells due to aesthetics" (Architect 2)
41) "There must be stricter requirements for how new buildings are to be built in the future" (Architect 2)
Costs
42) "We as architects can draw it and propose it, but those who sit on the money bags are more worried" (Architect 1)
43) "Architects care mostly about aesthetics and little about money, and everyone else does the opposite" (Architect 1)
44) "It is very important that BIPV is considered and included in the planning from day one" (Architect 2)
Builders
Experiences
45) "We have an ambition that is so high that if we are allowed to use solar cells in the facade, and if it makes sense and there is a lot of sun on the facade then we do it" (Builder 2)
46) "In order to manage the Paris agreement, we must to a greater extent look at the rebuilding of existing buildings, the conversion of buildings" (Builder 1)
Challenges
47) "Norwegian architects need to learn solar cell technology, and what we can use this for" (Builder 1)
48) "There are still a lot of architects who think aesthetics come first, and then energy comes last. But clearly integrated energy design is about both things coming first" (Builder 2)
49) "I often experience that the architect draws a building and places it on the building based on where the planning authorities may want it, and then they might not think about how the building faces the sun" (Builder 3)
50) "It seems to me that architects are a bit afraid of what is new. What has not been included before is scary" (Builder 2)
Politics
51) "I think that when politicians give the signals they do, we are the operational tool to help them achieve what they have said" (Builder 2)
52) "The Planning and Building authorities have made projects a bit difficult for us sometimes, where the aesthetics are more important than environmental measures" (Builder 3)
53) "It is a challenge with today's understanding of aesthetics, and the Planning and Building authorities had major objections to how BIPV on one of our project was originally designed" (Builder 1)
Costs
54) "It's about contractors and consultants getting used to new requirements, and then it does not cost that much more any longer" (Builder 1)
55) "There was a great cost associated with the aesthetic solution used" (Builder 2)
56) "Everything is possible to do with BIPV, but price is a barrier" (Builder 3)
57) "People are afraid of losing large sums of money" (Builder 1)
58) "In an ideal world, it should not be that in the construction projects you are first and foremost controlled by the fear of losing money. Or the greed of making a lot of money. But then you move very much into an ideal world where everyone should cooperate and be good friends, a win-win situation" (Builder 1)

Table 4.2: *Summary quotes soft challenges continued.*

4.3 Standards

The aim of this study is to assess what is needed to make people use standards and what role standards play in the development of BIPV technology.

4.3.1 Experts

A need for good standards is emphasised by one of the informants since BIPV is still a niche technology, and there might be standards that don't exist which will make everything more complicated (Table 4.3, s.1). Some standards seem to be well known in the sector, while other standards might be complex to use or understand (Table 4.3, s.2). One informant mentioned how the lists of standards are lengthy and that there is no orderly overview over the standards available (Table 4.3, s.3).

4.3.2 Suppliers/installers

One of the informants mentioned that there exists a separate BIPV standard but there is as yet little indication of it being used in the industry (Table 4.3, s.4). One informant wanted to emphasise that standards could be a mess and a lack of system makes it difficult for the user. Many informants have touched upon the same ideas about the need of a simplified system (Table 4.3, s.5). One of the informants mentioned how there might be a need for more clarity regarding the standards covering BIPV and this is a topic the majority of the informants working with BIPV demand (Table 4.3, s.6, 7). Several informants have mentioned the necessity of operating with European standards in order to be competitive in this market(Table 4.3, s.8, 9).

4.3.3 Architects

One of the informants highlighted that standards provide security for the installers and the customers (Table 4.3, s.10). Another informant emphasised that today the solar cell market generally cooperates and buys products on the European market. In order to continue making this process easy for everyone there should not be too many special stipulations from Norway (Table 4.3, s.11).

4.3.4 Builders

There is a general agreement from several suppliers/installers, architects and builders on the lack of standardized BIPV products on the market. It will then make it easier to be competitive on the European market as well as being able to drive down the costs (Table 4.3, s.12, 13, 14).

Table 4.3 Standards
Experts
1) ”We need good standards. Everybody uses standards, but the thing is that when the standard does not exist you have to adjust between two areas of expertise. If you have good standards you could just follow it and it is fine” (Expert 6)
2) “Some standards are obvious, but what is challenging about standards is that some are very complicated or they might be overlapping" (Expert 2)
3) “I have the impression that people only read what they need regarding standards" (Expert 4)
Suppliers/installers
4) "There exists a separate BIPV standard but it is not one that is often mentioned really, it came in 2016 and has not been much referred to so far" (Supplier/installer 2)
5) "There should be a simplified system. Something that brings out the most important standards" (Supplier/installer 4)
6) ”There may be a need for more clarity over which standards are important when considering that solar cells also become building materials. What do the solar cells suddenly also have to fulfil then?” (Supplier/installer 1)
7) “It could have been necessary with an information page that shows exactly what needs to be done and not done, and what is needed” (Supplier/installer 6)
8) "It would be very helpful if there was a common standard that applies to the EU, especially when we trade with markets outside Norway" (Supplier/installer 3)
9) If we are to relate to Norwegian standards and they deviate greatly from the standards that the industry is used to using from before, it would have created more problems than it would have been easy” (Supplier/installer 4)
Architects
10) "Standards are very important because it provides security" (Architect 1)
11) “I think that it is important that you do not make very many special requirements for electrical systems. They should not deviate from other European standards because it will make it difficult for the technology to evolve” (Architect 2)

Table 4.3: *Summary quotes standards.*

Builders
12) "There is a lack of standardized products in this technology to make it more widespread" (Builder 1)
13) "It is always easy for those who plan and design buildings to be able to choose off-the-shelf products" (Builder 2)
14) "If you develop something new, it often becomes very expensive. Delivery reliability is also very important for Norwegian contractors. And then some form of standardization will make it much easier for the architects who design the building. It is about information and making visible what opportunities exist" (Builder 1)

Table 4.3: *Summary quotes standards continued.*

4.3.5 Quantitative survey following the interviews

The purpose of the quantitative study was to find out what can be done to improve the availability of the BIPV standards. The majority of the informants emphasised the need of a simplified system that would make it easier to use the already existing standards. The survey was sent to the informants already participating in the interviews for the thesis, and they were also allowed to forward this survey to other people they thought would have some opinions on this.

The informants got three answer options about what they thought could be done to improve these standards. One option was a diagram with click on possibilities to find the most important standards and an example of a diagram made by another standard committee was shown. This diagram is illustrated in Figure 4.2. Another option was a list of the most relevant standards in an excel document. The last option asked if the standards are satisfactory today.

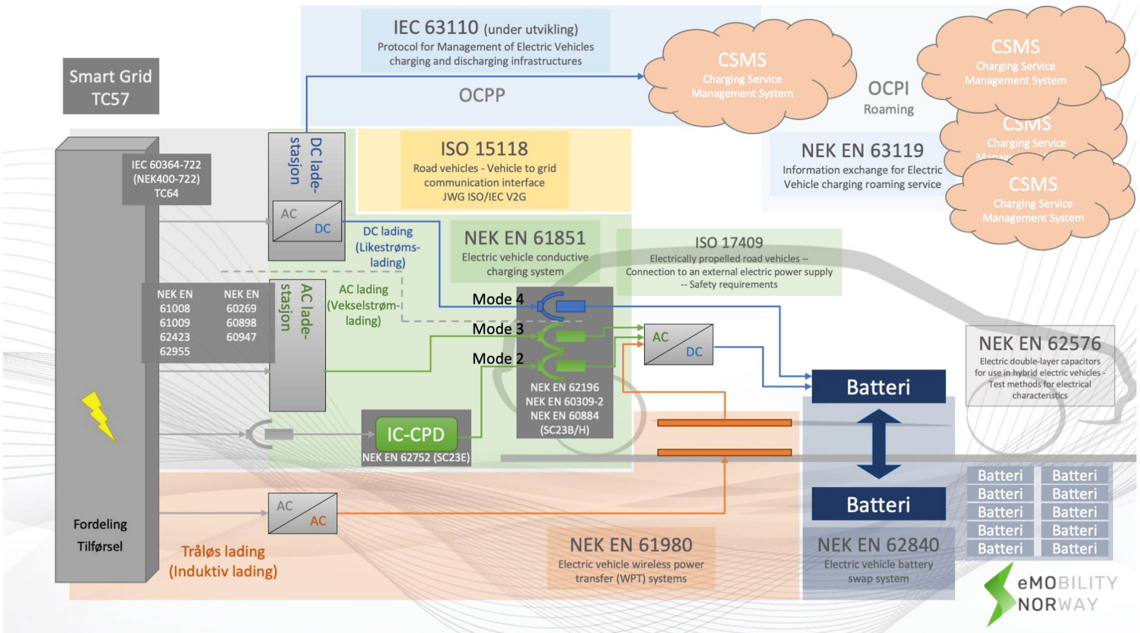

Figure 4.2: *Diagram used in the survey including click on possibilities. Visualization of available standards example, Jan-Tore Gjøby, E-mobility Norway [65].*

The results from Figure 4.3 show that 100% of the participants chose the diagram with click on possibilities.

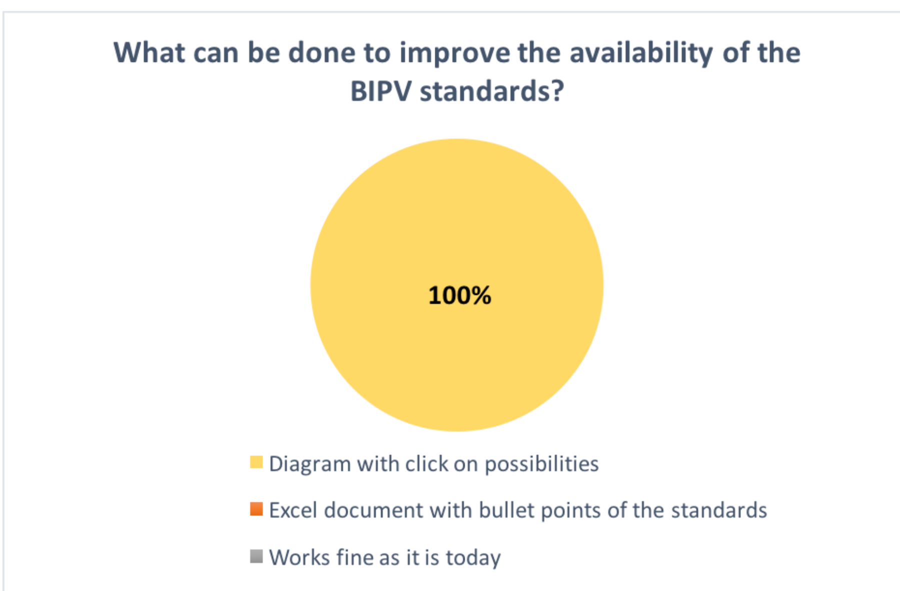

Figure 4.3: *Survey availability BIPV standards.*

4.4 Additional information

A separate section about neighboring countries and Estonia will be presented because this information will present how the situation appears to be in other countries in order to compare to Norway's situation. The information about neighboring countries has been provided by the informants in Norway, while the section about Estonia includes answers from an interview with two informants from a company in that country.

4.4.1 Neighboring countries

To get a better understanding about Norway's situation regarding solar cells compared to other countries, the informants highlighted what Norway's neighbouring countries have done in order to make solar cells more favourable. It is evident that incentives and subsidies are important for growth in new technologies. Several informants raised the importance of Norway's historically low electricity prices thanks to availability of hydropower (Table 4.4, s.1).

Sweden
One informant mentioned how Sweden has had a clear strategy for solar cells for many years and this has definitely helped push the market share of the technology and helped raise awareness in the country (Table 4.4, s.2). Another informant specified Sweden's well developed subsidies schemes which are a unique opportunity to increase the market share of solar cells and to make it more affordable for the consumers. The informant also touched upon the ROT deduction that has been introduced entitling a tax write-off to customers when renovating their houses (Table 4.4, s.3).

Germany
Several informants pointed out that Germany has also had very good subsidies schemes on installing solar cells (Table 4.4, s.4). Another informant wanted to emphasise the advantage the customers have in Germany regarding the electricity they deliver back to the grid (Table 4.4, s.5). This informant wanted to highlight that the output of electricity from solar energy is much higher in Germany compared to Norway. Despite this, Germany still subsidises support schemes (Table 4.4, s.6).

4.4.2 BIPV in Estonia

One of the interviews included an in-depth interview with a solar cell manufacturer in Estonia. A foreign company was included to get an outside perspective in relation to the Norwegian information collected from various actors. Two people from the company were interviewed in order to get more insight and perspective. They will be presented as informant 1 and informant 2.

Experiences
One informant talked about their experiences with BIPV, and how people in Estonia have readily accepted the technology in the market (Table 4.4, s.7, 8). He further specifies the importance of close cooperation between roofers and electricians when installing BIPV because they have the impression that not many companies have this knowledge. (Table 4.4, s.9). They also mentioned that it has been challenging finding a suitable framework for the modules and this is something that they have been able to solve (Table 4.4, s.10).

Costs
One informant emphasised that BIPV might not be that expensive and gives an example of a Norwegian project that saved money by installing BIPV on the roof (Table 4.4, s.11). The informant underlines that costs seem to be an issue but it has been proved that BIPV is not always more expensive than a BAPV project (Table 4.4, s.12).

Aesthetics
An interesting finding in Estonia is the acceptability of BIPV on historical buildings and not BAPV modules. The reason for this is that BIPV can easily be integrated into the buildings and the original look can be preserved (Table 4.4, s.13).

Politics
The informants were very clear about the importance of support schemes (Table 4.4, s.14, 15). One informant emphasizes that Estonia has had a lot of subsidies for renewable energy projects in the past (Table 4.4, s.16, 17). They still have various support schemes for everyone renovating their houses into a more energy-efficient one, whether it is changing the heating system or renovating facade or roofs.

Technical challenges

Fire safety remains an important topic regarding technical challenges with the BIPV technology and the Estonian informants shared information on how they dealt with this issue (Table 4.4, s.18).

Table 4.4 Additional information
Neighboring countries
1) "The solar cell installation must be a lot cheaper for it to be worthwhile to do it in Norway since we have such cheap electricity, and we have relatively expensive taxes on labor" (Supplier/installer 4)
Sweden
2) "Sweden has had a national solar-electric strategy since 2014" (Expert 1)
3) "Sweden has a very good subsidy for an installation of BIPV. Here you have something called ROT deduction, and that means that if you do something with your house, for example change your roof, you can write it off on your tax as a ROT deduction" (Supplier/installer 3)
Germany
4) "Is more profitable with BIPV in Germany due to their tariffs" (Expert 5)
5) "In Germany, they have realized that you must first get a discount on the grid rent, and that you must get a good price on what you deliver back" (Expert 4)
6) "Norway has 0.02% of its electricity from solar energy and Germany has 7-9% from solar energy and Germany still has support" (Expert 4)
BIPV in Estonia
Experiences
7) "I think we have made a lot of impact in terms of accepting BIPV in the market" (Informant 1)
8) "Entering new markets you are faced with different agendas and then the people have different ideas on how solar works and we just need to get rid of the fears that people are having and that is one of the biggest hurdles to overcome" (Informant 1)
9) "We have the impression that not many companies have this knowledge between roofers and electricians internally" (Informant 1)
10) "It might be challenging to find a suitable framework, but we have solved this with a framework solution that can be used to any module size and it will be water tight" (Informant 1)
Costs
11) "Eventually the customer paid 20% less than if he was to renovate the full roof and put solar on top of it" (Informant 2)
12) "The issue with BIPV is that everybody thinks but nobody knows. When people say it is expensive, we say how much is it compared to what?" (Informant 2)

Table 4.4: *Summary quotes additional information.*

Aesthetics
13) “There is no way you can install standard panels on historically buildings, but you can install BIPV" (Informant 2)
Politics
14) “The attractiveness to go solar is driven based on what schemes you have in different markets” (Informant 1)
15) “Estonia is dependent on the European regulations and the only way to push towards the carbon neutral standards is policy enforcement, to make the laws the way that solar or other renewable energy technologies have to be installed, is the only way” (Informant 2)
16) “In Estonia in the past years we have had huge subsidies schemes for renewable energy projects that were enforced, unfortunately it ended last year, but that was a huge boost for solar“ (Informant 1)
17) “We still have a scheme that states that if you are to renovate your old house into a more energy-efficient one, then you will get 30-40% discount. The government would pay this directly“ (Informant 2)
Technical challenges
18) "The safety issue is quite important when considering BIPV" (Informant 2)

Table 4.4: *Summary quotes additional information continued.*

5 Discussion

5.1 Technical challenges

Fire safety

One finding highlighted by the informants and confirmed by literature is the importance of firefirefighters' awareness of a photovoltaic system on arrival at an accident. This will ensure that the crew will not be injured during extinguishing [55]. It is also becoming more essential for everyone in the solar cell industry to be aware of what must be done to ensure the safety of the firefighters in the event of an accident. The regulations state that a photovoltaic system always has to be clearly marked, and this applies to both industrial / commercial buildings and detached houses. The entrance should be clearly marked, stating that the building has solar cells.

There are claims that fire in BIPV modules differs from a fire in a BAPV facility. A German study from 2013 examining 180 reported fires showed that in BIPV ignition was more likely to occur. BIPV also caused damage to buildings in those cases where a fire broke out [57]. In 2013, BIPV was such an immature technology that the study is not entirely representative. This shows that there is a massive knowledge gap on this topic that is worth investigating. This also reflects on what is stated in the literature review on fire safety. A report states that BIPV systems have a 20 times higher risk of fire incident than for BAPV systems [50]. Due to lack of studies on this topic there is reason to criticize the high numbers.

Another finding is that fire safety and BIPV are not seen as a problem among those responsible for the facility. As a supplier of solar cell mentioned on a webinar, there should be no worries regarding the installations as long as the standards are followed [52]. The majority of the actors seem to have a good overview of which guidelines to follow. When considering solar cells in general, it is routine to have a dialogue with the fire department in large projects, while not for smaller projects. However, there seems to be no dialogue with the fire department concerning private buildings and the installers are expected to follow the regulations. The findings of this thesis show that the firefighters should have more knowledge about solar cells and fire safety so that it will be safer and easier for them in the event of an accident. This awareness of fire safety seems to become even more important with the expected increase in BIPV installations in the years to come. Figure 5.1 shows a summary of the findings of fire safety and BIPV.

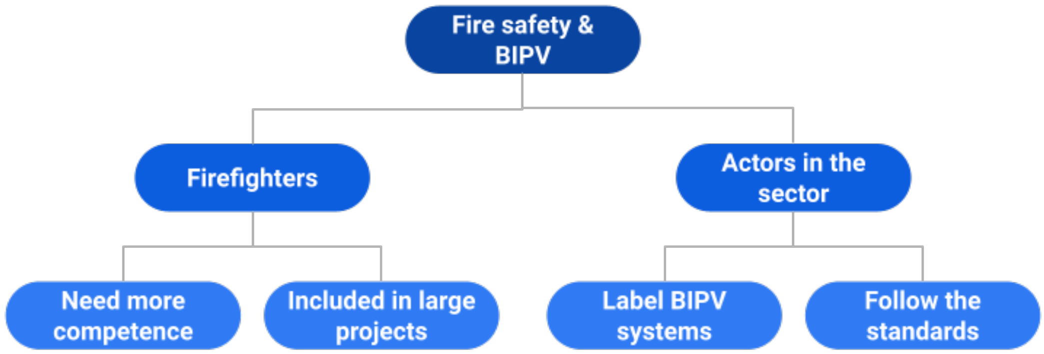

Figure 5.1: *Findings fire safety and BIPV.*

Shading

With careful planning, shadow sources can be minimized in order to maximize the incoming solar radiation in a more efficient way. This is done with the help of simulations where both daily and annual trajectory of shadows are taken into account [48]. It will then be possible to optimize the system with respect to the position of the modules and the orientation and cubature of the building. Several informants have stated shadowing as a problem for BIPV and that this must be carefully considered. A major disadvantage with BIPV on existing buildings is that the modules have to be laid according to the structure. Module design and the electrical connection of several modules can have a positive impact on the shading. It is essential that people who work with this technology have the expertise needed to provide a better performance for the facility

Inverters

The inverters seem to be more challenging to plan on a BIPV installation. As some informants have mentioned, it is important to consider the way the inverters and the modules are inter-connected. Inverters or power optimizers could be used depending on the project. If shading is a problem, then micro-inverters or power optimizers are the preferred solution due to maximum power point tracking (MPPT) on each module and not per string. If the MPPT was on each string, the entire string would be affected by partial shading on a small part of the string. A module level converter (MLC) will increase the flexibility of the installation but problems arise if there is a need to replace inverters that have failed during operation [25].

This shows the importance of having valuable knowledge of the various technologies, in order to know what will be best suited for a specific project. Which inverter should be chosen depends on the project itself, and price can also have an impact. The lifespan of the inverters will also affect the installation and failures can occur which can cause complications in a project.

Replace and repair modules

As stated in the literature review, PV modules degrade over time and unfortunately might fail [19]. Difficulties arises if there is a need to replace BIPV modules [44]. The reasons are many, but as one of the informants said, there is a problem regarding the customized modules.

By talking to various experts in this field, the feedback is that one or two extra customized modules are normally ordered in case there is a failure. The problem arises if a large area fails, and several modules need to be replaced. An issue that could occur is that a module type is removed from the product catalogue of the supplier. This impacts the string design and the system does not produce as it is supposed to. Another issue is that if needed to replace a module after some years, a mismatch may occur because the operating modules will be degraded. These losses occur when modules don't have the same identical properties. The output will be dominated by the solar cell with the lowest output, so mismatch losses are a problem for PV modules in general [66].

Several of the experts and the installers think there is insufficient knowledge about repair and replacement of modules due to lack of expertise and unstructured planning. This is also more challenging for BIPV in projects where customized modules are used. One informant mentioned that a company making some customized modules went bankrupt leading to several questions about how to handle maintenance and a possible replacement of the modules.

Simulation

BIPV projects are often very complex projects in the beginning, with multiple orientations and sizes to be taken into account. The development of models and tools to optimize design and planning is seen as a necessity for a complete interaction between solar cells and building fields [44]. This was further investigated during the interviews. One informant expressed that the difficulty of simulating BIPV arises because the majority of BIPV modules are custom made. In most cases products that are available in the libraries of simulation software tools will not be able to be used. The electrical characteristics of these modules will therefore be given to the supplier after the modules are produced. This key factor complicates the simulations of BIPV systems. With the facade in mind, he further emphasised that the amount of incident radiation depends on the building surroundings. This indicates that a 3D model of the entire area around the simulated building should be included in the simulation and this can be very difficult and costly to obtain. This may indicate that it would have been useful to develop better simulation tools specific to BIPV for the industry. Simulations of BAPV facilities seem to be much more straightforward, and several informants have mentioned that they use the same program to simulate BIPV. This could have a major impact on the results. In order to make the job easier and more accurate in the years to come, and with an increasing number of BIPV installations, a better tool will be beneficial for the actors.

Thermal regulation

Thermal regulation has been discussed as an issue with BIPV modules. This might influence the efficiency of the modules since the modules work better when the temperature is low [40]. As one of the informants mentioned, iterations have to be done in order to figure out what is most important for a specific project. Ventilation is an advantage because it increases the efficiency of the modules, but it will also lead to a loss of thermal insulation of the building. Depending on the project, specific solutions have to be made depending on demands from customers.

Testing the performance

One informant emphasised that the cost of testing BIPV modules is very expensive. All crystalline silicon PV modules should be certified according to the IEC 61215 series and this standard contains climate tests, electrical characteristics and a mechanical load test [67]. The suppliers have to pay a laboratory to perform these tests. BIPV modules prove to be more costly while standard PV modules are more reasonable since the suppliers will produce huge quantities of the same modules.

Since BIPV modules are usually custom made for a specific project, it is more complicated to test the modules with a solar simulator which also increases the costs. Some solar simulators might not fit the customized modules and if the modules have to be tested in an outdoor environment, this might confuse the data [49]. It may be necessary to develop solar simulators that are easier to adapt, to be able to handle all the new BIPV installations that are expected in the future.

Monitoring the performance

Monitoring seems to be challenging as highlighted by several informants. Monitoring is often done with a switch inverter, and it can easily detect big problems. When it comes to smaller problems the inverter will not detect this and a thermal imaging (IR) camera has to be used. Thermal imaging cameras are mostly used to detect defects on the modules [68]. Major problems could include solar inverter failures, micro-cracks or wiring damage [69] while minor issues could include dirt, dust and pollution [70].

As one informant mentioned, when considering BIPV on the facade there can be difficulties figuring out when failures occur. Monitoring on a facade is complicated since the temperature sensor will be impacted by the inside temperature, and this will give incorrect measurements. The owner of privately-owned buildings is responsible for ensuring that the facility works properly. Small errors can be difficult to detect and this is a problem when owners lack the interest and the competence to discover these. For the majority of the projects, there is no requirement for the actors responsible for the installation to check that the plant works or produces correctly after finishing the project.

Monitoring on commercial buildings with PV systems is routinely conducted by professionals to ensure that the facility is in working order. One of the informants emphasized that the company providing the BIPV modules accepted less monitoring, because energy is not as important on a BIPV facility compared to a solar park where the only focus is energy production. This is because the projects are seen as a mixture of energy production and building materials and it is not always possible to take energy production into account at every time. This shows that it is important to remember that BIPV actually replaces conventional building materials, and although it also produces energy, it also has other extremely important functions. For BIPV, monitoring is also crucial, but at a completely different level.

Responsibility

Responsibility needs to be highlighted and it is crucial for the actors in the sector to be acquainted with this issue. One of the informants has been involved in a situation where responsibility became an important topic to discuss. It involved a solar power entrepreneur and a facade entrepreneur. A solar entrepreneur is needed providing the solar part of the facade, but the mounting systems, isolation and waterproofing for instance, is done by the facade entrepreneur. Cables run through the system which is the responsibility of the electrical entrepreneur. If something goes wrong, who is responsible? This is something that is not apparent in the BIPV sector. When adding BIPV, both the electrical industry and the construction industry are involved. There have to be special juridical agreements drawn up to accommodate everyone. The same informant wanted to emphasize that this is a time-consuming process and requires a lot of technical input.

In view of the fact that BIPV falls between two areas of expertise makes this technology more challenging and there is a demand for clear guidelines. This important finding is illustrated in Figure 5.2. Developing good standards will be useful for everyone working with this technology in the years to come. This also means that the industries must cooperate more in the future, and learn from each other so that they understand the entirety of what needs to be done.

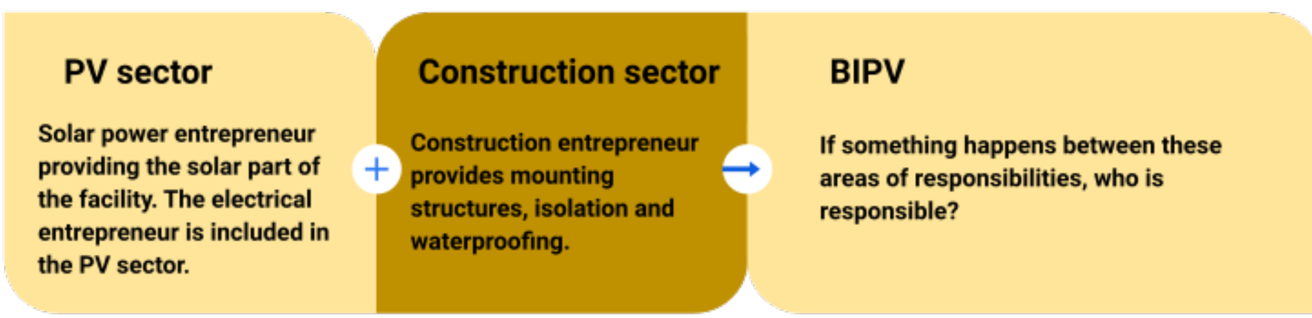

Figure 5.2: *Who is responsible?*

5.2 Social challenges

Experiences

An important finding that has not been described in literature is the fact that some suppliers/installers find it more difficult to work with BIPV than others, based on the companies' background, illustrated in Figure 5.3. For instance, a regular solar cell company had to learn more about the construction process in order to be able to get the roof or facade tight. This job seems to be easier for companies who have historically been working as roofers or facade contractors and have all the knowledge needed to be able to do an efficient and secure mounting. Many informants stressed this point. BIPV is very different from a BAPV installation, and as one of the informants mentioned the precision level is much higher than on a conventional solar cell installation. If a solar cell installation company that usually works with BAPV switches to BIPV it will discover completely different requirements for accuracy. It becomes more apparent if something is not completely accurate.

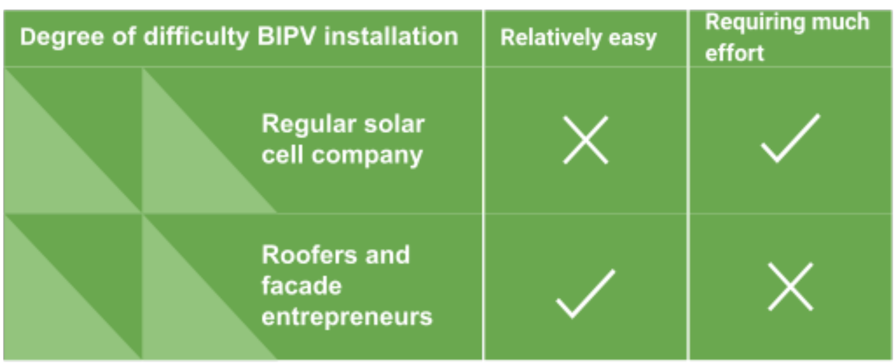

Figure 5.3: *Degree of difficulty for a BIPV installation.*

Challenges

BIPV technology is not yet that widespread and lack of competence and knowledge from consumers and professionals in the sector make assessments necessary in every project. Lack of competence regarding BIPV is reflected in the majority of the actors in the sector. The lack of knowledge is also reflected in private individuals, who are not aware of the solutions that exist because it is difficult to find the information. According to the architects interviewed in this field, some people are sceptical to solar cells because they don't like the appearance and do not know the possibilities of BIPV. Based on the informants' experiences, BIPV is most suitable for people with expertise from their own work or interests. This also confirms what is stated in the literature review about the need of advertising BIPV products and solutions in the market to make people aware of the solutions available [44].

Multidisciplinary is also considered challenging for BIPV. An interesting finding historically linking the cooperation between design, construction and the electrical industry makes one question why multidisciplinary is challenging for BIPV. It is a natural process that electricians work in a building together with the construction workers. As stated in the literature review, it is necessary to reach an agreement between economic considerations, aesthetics, requirements for building regulation and between optimal operating conditions [48]. This shows the importance of the cooperation between all parts involved as illustrated in Figure 5.4. Working with BIPV is more difficult because there is a need to work at a more detailed level when working with this specific technology. When it comes to solar cell suppliers, their responsibilities are different depending on the project. In some projects they are also responsible for part of the construction technology, while at other times they have no special responsibility here. This also confirms that suppliers and electricians need more expertise in the construction technology since they occasionally take responsibility for the actual installation of the photovoltaic system. As for BIPV, it is clear that the interface between disciplines is still challenging for the actors in the industry. Generally most people think it is possible to carry out BIPV projects, but the fact that more multidisciplinary is required with this technology makes many people uncertain about starting a project.

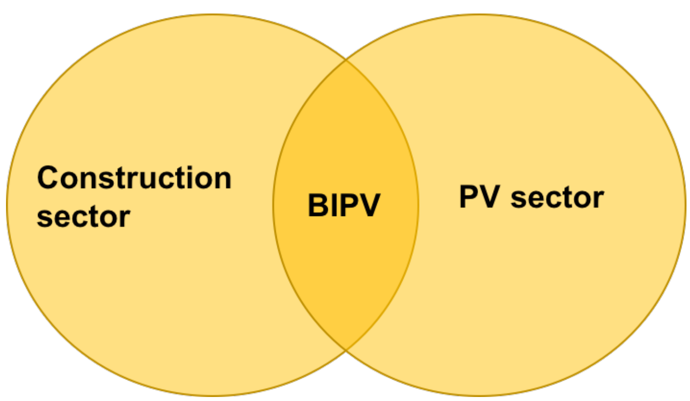

Figure 5.4: *The need of close cooperation between construction sector and PV sector when working with BIPV is reflected in this figure.*

An important finding is that actors working with BIPV have different opinions about how to improve competence, illustrated in Figure 5.5. Architects believe that the construction industry has limited competence about solar cells and BIPV, while builders believe that architects and suppliers/installers must improve their competence. The suppliers/installers also find it important that the architects and builders get more competence about BIPV in general. This finding indicates there is a need for a better cooperation between all parts involved and that everyone has to learn more about the other responsibilities in order to complete a more efficient BIPV installation.

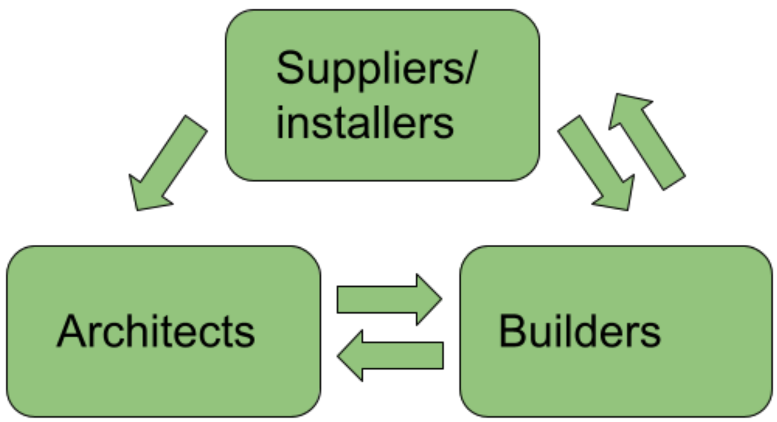

Figure 5.5: *Shows the need of increasing competence.*

The architect informants mentioned how they can draw and propose BIPV, but it is difficult to get a breakthrough because the builders will retain their methods as long as possible. On the other hand, the builders believe that there is a lack of competence among architects which might influence the choice of location of the PV system, especially when considering it on a facade. One supplier/installer mentioned how beneficial it was for them that architects and builders are aware of the opportunities that exist. The suppliers/installers often come into play when the solution is already decided. Generally they have no way of controlling this, unless they participate in commercial projects where they are involved in the planning process.

It is also evident that the construction industry is conservative, and the majority of the informants agree on this. It is also understandable since they have to deal with risk management and finances. One of the informants told about his responsibilities as a builder which included making decisions and paying bills. He went on to emphasise the need for suppliers/installers to learn more about the construction process, and what consequences it has for the actors when they offer their BIPV solutions. Sometimes those who offer the solutions are not the same as those who takes the risks. It is important to be acquainted with this for all actors working with this technology.

From the findings it is evident that the installation of BIPV systems is specialized. It was interesting to get an insight into the different aspects that have to be taken into account when installing these facilities. Compared to BAPV, it is a totally different process from beginning to the end, and requires a deeper understanding and more cooperation between different actors. There are more people involved from different sectors that need to cooperate and plan this as efficiently as possible. It is also very important to spend more time in the planning to avoid that things go wrong. When using BIPV, it is also demonstrated that it is important to consider it early in the planning phase. Several informants have mentioned that they have experienced in the course of the projects that some new aspects arise that they had not envisaged. This can make the project more complex and costly.

During the installation of the system, it is very important that everything happens in the correct order. If not, it might lead to the removal of all the modules and repeat the installation. This will increase the costs of the project as well as making it a time-consuming process.

After the installation is completed, a building inspection is important to check if everything is done properly. It is also important that the owner who is responsible for the installation of the facility makes sure that all the standards are followed. There have been a lot of mistakes regarding the documentation of these facilities, and this problem could be avoided by raising awareness. It is recommended that the fire department should become more familiar with solar cells facilities, and learn more about the BIPV technology in order to know what to do in case of a fire accident.

Table 5.1 shows the importance of what has to be done when planning, during and after the BIPV installation.

Planning	Important findings
Before	• Multidisciplinary • More accurate planning • Detailed simulations • Double-check measurements
During	• Follow the standards • Must be done in the correct order
After	• Inspection

Table 5.1: *Important findings when planning, during and after the BIPV installation.*

Aesthetics

BIPV is a technology that provides a pleasing architecture where solar cells are not always seen [21]. It resembles conventional building materials, and there are plenty of different solutions available on the market. As stated in the literature review, BIPV is also very flexible in terms of design and can be customized for all projects [49]. It is important to develop products that are attractive for architects in particular. Today, there is a great interest in coloured modules and by increasing the flexibility of different shapes and sizes of BIPV the aesthetics of the building may be enhanced [44]. The introduction of a colored facade panel that looks like any other conventional facade panel, would be more attractive and the architects might become more interested. It is important that the market develops design products that move standard products to a new level. Currently, they have entered the market, but there is a need for greater variety.

The choice of BIPV is more logical when renovating or building a new one. An interesting finding was that some people actually chose BIPV even though they had a new roof mounted. These people find this technology more attractive and want to integrate BIPV modules into the roof instead of installing BAPV on a new roof. This shows that many people care about aesthetics, especially when considering solar cells on their roof. This may indicate that BIPV will also become more widespread as soon as the actors raise awareness of what technologies exists.

Politics

There seem to be many factors that will affect the implementation of more BIPV systems in Norway. An important factor one of the informants touched upon is that there has to be market push and market pull. It is important with new technologies that they get promoted by people in the sector, as well as some political push that might help the development a step in the right direction. Market pull also plays a significant role because consumers need to accept the technology which has to be attractive in order to be competitive.

There are few incentives to choose solar cells in Norway. Support schemes and a plan from the authorities about what they really think about the green shift have been demanded by the informants. Regulatory barriers also have a major impact on the implementation of solar cells in Norway. One example of this could be a commercial building, where only a small part of the roof can be built on. It could be more convenient to expand the facility and be able to sell excess power to the neighboring buildings. The electricity could be shared with neighboring detached houses that are located nearby. This is not possible today because of an obstacle in the energy law related to the sale and share of excess solar electricity. In Norway, it is not profitable to have a solar cell system that is larger than what is needed because of the amount of money earned from selling solar electricity to the grid is quite low [71]. For a regular household, for example, that uses 15,000 kWh a year, it does not pay to have a facility that can give that. BIPV could have been used on big commercial buildings on the roofs and facades, but these obstacles do not make it profitable.

Some of the informants have pointed out that there have to be stricter requirements for the construction of buildings in the future. If a house has to produce a large amount of energy for one's own use, this will make solar cells and especially BIPV very attractive. One builder interestingly pointed out that when politicians send out signals by showing little interest for solar cell technology and no clear strategic direction on how to build energy-efficient buildings, the builders must be the operational tools to help them achieve what they have said. Having this attitude is probably very crucial to be able to take part in the important changes expected in the future. Further development in the industry is dependent on individuals or companies choosing to take the lead and stand out, test new things, and show off projects.

The Planning and Building authorities have caused some frustration around their policies concerning solar cells, and even have rejected several BIPV projects due to aesthetics. The builders and architects consider it is a great disadvantage if they put aesthetics in front of the environmental goals that the projects have. The implementation of solar cells on protected buildings has also caused dissatisfaction. BIPV is a technology that can be integrated and customized for every project, and hopefully will gain more market acceptance from everyone as soon as the solutions show what potential it has.

Most of the informants pointed out that it is necessary for buildings to look different in the future due to a large investment in other energy sources. It is then very important that the authorities are driving forces for the technologies so that they are able to grow. The solar cell industry has not had the same possibility to grow as the solar cell industry in other countries due to regulatory barriers and a lack of incentives. Experience from other countries shows that support schemes are important, and should be long term. It is important to start at a high level in order to be able to create growth, and the decrease should take place over time when one has a clear strategy [6]. Table 5.2 illustrates the barriers and what is needed for further development of BIPV technology.

Barriers	Needed for further development
• Regulatory barriers • Lack of incentives	• Support schemes are important • Authorities should be the driving force • Stricter requirements on how to build new buildings

Table 5.2: *Summary politics.*

Costs
BIPV is a technology that is not yet considered economically profitable as shown in the literature review when comparing the cost for different technologies [42]. This is one reason why it is used mostly in energy-efficient buildings. What is important to remember is the electricity production in return, which is not the case for conventional building materials. BIPV also gets calculated by costs per square meter, and when taking this into consideration the system costs are no longer that high. It can be more acceptable that BIPV is more expensive since it has two functions [29]. An important aspect to keep in mind when comparing the price of BIPV is what it costs in relation to other alternatives that are considered in a construction project. If a building is in a situation where a roof must be replaced, and the customer wants a slate roof, BIPV will not necessarily be that much more expensive. Whether it becomes profitable or not therefore depends on the customer's alternative. In most cases where the customer is looking for a cheap roof, BIPV will not be the best solution. However, there has been a lot of research on estimating the price in the future, and this will drop significantly affecting the solar sector positively [41].

As the architects mentioned, they can draw and propose BIPV, but the economic situation will determine the demand. The builders are often more concerned because of the fear of losing money. In large projects where BIPV is proposed, the builders have the responsibility of paying the bills. It is also important for them to make a profit. It is difficult to create a win-win situation for everyone with respect to how the market operates. It is therefore important to recognize the value of understanding each other and try to cooperate as efficiently as possible.

As one informant concluded, it's about contractors and consultants getting used to new requirements and then the technology becomes more economical. To draw a parallel, this is also how the Enova support scheme works. Some years ago Enova supported the implementation of passive houses. Now passive houses have become a requirement in the Planning and Building law [72]. Industry has learned to build passive houses in such a way that it is no longer an expensive element in the project and the same development can be seen for solar cells. The solar cell industry has not only become better at designing and delivering, but also the solar cells have become more efficient.

5.3 Standards

Most informants are familiar with and have used NEK 400:2018. Other standards are difficult to navigate, and it is difficult to know what standards exist and what they require. There is a need for more clarity in order to make it easier for the users of standards. Which ones are relevant to the individual business can be difficult to determine. Several informants have emphasised that the standards are difficult to find because the website containing these standards is so unstructured. In both national and international standards this unstructured data is evident making it difficult to navigate. Good and comprehensible standards will therefore be of great importance to the BIPV industry in the future.

As mentioned in the literature review, the first BIPV standard EN 50583 was published in 2016 [44]. EN 50583 does not seem to be well known in the PV industry or the building industry as findings show that it is infrequently used. The findings highlight the need for availability and work on getting more harmonized standards. Standards are an important tool for a growing market, and if the standards are inadequate, they will not be used to the same extent.

Some informants have mentioned that it has been challenging to find standardized modules resulting in having to spend time, effort and money finding products on the European market. Standardized BIPV modules are something almost all informants require. This would make it easier and cheaper to use the technology. It would be easier to use modules from different manufacturers. Similarities of connections and technical construction would make it possible to use elements across suppliers and providers, which would improve security of supply and give all manufacturers a place in a complex market. Standardized modules can make repair and replacement easier if a problem occurs on part of the facade or roof after 1-2 years.

According to the literature review, there is a demand for further development and work on getting more harmonized standards [44]. This has also been confirmed during the interviews. A majority of the informants mentioned the necessity of having standards that correspond to the European standards. Most of the manufacturers of solar cells are located outside Norway making the use of similar standards easier to deal with. With harmonised standards with Europe, it will be easier for Norwegian companies to find products on the European market that will be acceptable in Norway. Standardized modules and standards corresponding to the European ones will ensure market access to the actors working in the solar energy sector.

Standards are necessary because they provide security and meet the authorities expectations of electrical safety [36]. This becomes important when considering new technologies entering a market. Precise instructions will be required to ensure that all small solar cell companies working with PV know what requirements apply if they are to attempt BIPV. It is important that the experts in the industry are involved in developing the standards that are needed, and that they also help make it easier to use the standards that already exist.

Several users of standards pointed out that availability is unsatisfactory and this is not because the standards do not exist, but because they are difficult to find. Creating a more relevant prioritization overview of standards has been demanded from the majority of the informants. Such a document would also improve the overview for the users of standards.

The small quantitative survey conducted for the thesis shows some important results about the availability of the BIPV standards. 100% of the participants chose a diagram with click on possibilities in order to improve availability of these standards. The reason for this positive response regarding such a diagram reflects the need of a tidy system that will give a better overview of how the standards are connected.

Another interesting aspect is the start-up of the JWG 11 which will combine the areas of expertise of ISO and IEC to work with BIPV [45]. These standardization organs have seen the challenges with BIPV and have decided to work in close cooperation to try solving these problems. This could be a solution to several of the challenges that the informants have talked about regarding BIPV technology. This work can help make it easier to offer BIPV solutions in the coming year and help ensure access for the solar energy market.

5.4 Additional information

5.4.1 Neighbouring countries

Support schemes seem to be the biggest difference when comparing Norway to neighbouring countries. Norway appears to lack support schemes for PV and BIPV. Other countries in Europe have had more support for BIPV than a regular PV installation and recognized in the early development phase that people needed extra funding. With financial-assistance Sweden has built 7 times more solar energy installations than Norway [73]. This indicates that incentives have to be given in order increase the market share of solar energy in Norway.

Norway already has around 90% carbon free electricity production from hydropower [2], and important to remember Norway is part of the European power market [74]. The fact that Norway has less expensive electricity than other places in Europe plays a major impact on solar cells development. Norway has cheap and green electricity, but a combination of solar cells and hydropower will provide great benefits. It is about expanding jobs and new value creation, which also has export opportunities. If Norway produces cleaner electricity, it can replace dirty electricity elsewhere. Solar cells installed in homes do not require any encroachment on nature. They normally pose no danger to local plant and animal life, do not make noise nor emit local air pollution [74].

Sweden has a good subsidy scheme for installation of solar cells in general. The first subsidy scheme started in 2005, covering 70% of the installation costs. In 2019, the support was reduced to 20% [75]. This support applies to all solar systems that are grid-connected. Sweden also introduced a tax saving scheme called ROT deduction. People are entitled to a 30% tax reduction on all labor costs restricted to 50,000SEK per person per year. The ROT deduction can also be used in other countries that are members of the EU/ESS if a Swedish citizen. These two support schemes can not be combined with each other [76]. Sweden also has a more expensive electricity price compared to Norway and the ROT deductions and subsidies make it profitable to implement solar cells.

In 2017, Germany produced more power from renewable energy sources than from coal [77]. They have had a major growth in solar energy and have realized the importance of a discount on grid rent and a good value on return delivery to the grid. There are regions in Germany that have demanded all new non-residential buildings to have solar cells [78]. Such extreme measures have yet to happen in Norway. Germany responded both considerably earlier and enthusiastically from the beginning. As one informant emphasised, While Norway produces 0.02% of its electricity from solar energy, Germany has 7-9% and still maintains the support schemes. Table 5.3 shows important findings when comparing Norway to neighboring countries.

Neighboring countries	**Important findings**
Sweden	• 20% subsidies • ROT deduction • More expensive electricity than Norway • More profitable selling electricity back to the grid
Germany	• Good subsidies schemes • Discount on grid rent • More profitable selling electricity back to the grid

Table 5.3: *Comparing Norway to neighboring countries.*

5.4.2 BIPV in Estonia

Experiences

BIPV is a niche technology and Estonia is a good example of a country that has used BIPV technology to its advantage. Even though Estonia is somewhat a pioneer in this, the Estonian companies have understood the importance of advertising and showing the products available to the costumers. They have been working with influencing the market and people's view of solar energy and the BIPV market as a whole. The sale of BIPV has dramatically increased tripling its sales in 2020. The challenges that are seen in Norway seem to have been overcome in Estonia according to both informants.

One of the experiences the Estonian informant specified was the need for a shift where all the existing solar companies need to go beyond regular solar cells installations and try to deal with roofing procedures. The informant further states that having different people coming from different fields and being able to deliver is the key component.

The informant also highlighted a lack of framework solutions in the market that can be adjusted to all kinds of modules. The Estonian company has the compatibility with their frames to support advancements of different combinations and click-on solutions. They are offering help to different producers of modules to find the correct framework in order to make the system water tight. In Norway, many informants have touched upon this topic, and these Estonian solutions might become more attractive in the coming years as soon as the market gets more insight. As long as people feel comfortable and see that the solutions work, it will become easier for companies to enter the BIPV market.

Costs

Another Estonian informant mentioned that the company in Estonia had completed a successful project in Norway using BIPV. The customer was going to change his roof, and by choosing BIPV the customer actually saved money compared to having to do the roof and BAPV on top of that. This shows that BIPV is not necessarily that much expensive than BAPV, but it does depend on the project and the surroundings where the installation will take place. What the informant further mentioned is that people listen to rumors about the costs of BIPV, and without this being corroborated by actual costs.

Aesthetics

As the informant emphasised, when renovating historical buildings, approval from the authorities is very important. It is important that these buildings should preserve their original look and the renovation can be 3-5 times more expensive than renovating a regular house. The advantages with BIPV are that they can be integrated and customized so that the modules will fit very well into the building. However, it is impossible to make historical buildings environment-friendly without changing this restriction. The approval of BIPV on historical buildings in Estonia is very different from Norway's situation. There have been some cases where protected buildings have gotten approvals from the Planning and Building authorities in Norway, but it is very seldom.

Politics

Solar energy technology has been helped by Estonia's membership to the European Union due to its goals in reducing greenhouse gases drastically in the years to come. The Estonian informants mentions the role of support schemes for technology adoption. There are various support schemes in Estonia for the adoption of renewable energy and the biggest one is opened once a year. In 2021 it opened on 1st of March 09:00AM and was closed approximately five minutes later because the funds ran out. The total budget was 1.3 million EUR.

Support schemes are also something that the majority of the Norwegian informants see as a necessity in order for growth in the market. In Norway, there has been a lack of such incentives. One of the reasons for this might be the hydropower Norway has, which gives the Norwegian citizens relatively cheap electricity.

Fire safety challenges

The importance of raising awareness for everyone regarding fire safety is a challenge within the solar energy sector. The Estonian informants emphasised what they have done in order to mitigate the fire risks for a BIPV facility. They only use inverters that have protection capability, in addition to optimizers to make sure that the voltage will not increase if a failure occurs in the system. The inverter will be able to detect all issues and shut the system down. One informant also mentions how this has taken away a lot of the questions they have been asked and a lot of fears. An effort is also made to provide guidelines for the local fire department. The same is done in Norway, and this has been an important procedure in order for everyone to become more comfortable with solar cells in general.

6 Conclusion

The purpose of the thesis has been to conduct a qualitative study where the topic covers challenges and standards within BIPV in Norway. The research was conducted to answer an inquiry from NEK. This is a mapping study which aims to be of use for all actors in the industry interested in the BIPV technology. To answer the research questions, 18 actors in the Norwegian market working with BIPV have been contacted, as well as a company from Estonia that produces BIPV products. This was done in order to answer the problem statement:

What are the challenges for BIPV technology in Norway and how can standards help ensure its access to the solar energy market?

Q1 What are the technical difficulties related to BIPV technology?
The major technological difficulty facing BIPV technology seems to be the topic of responsibility since BIPV falls between two areas of expertise. There is a lack of clear guidelines on what has to be done, and who is responsible if a problem occurs between the electrical and the building sector. This is an important topic to explore further in order to make it easier for the people involved in future BIPV projects. It could also increase the interest of several actors working with regular PV installations, as clear guidelines make it easier to start working on a project like this. The research also indicates that there is little research into the risk of fire in BIPV facilities. More effort is needed to make everyone more comfortable with the technology and what needs to be done if accidents occur.

Q2 How can knowledge, social and political influence affect the implementation of BIPV in Norway?
The findings indicate that knowledge, social and political influence will affect the implementation of BIPV in Norway. Highlighted issues are lack of competence and challenges due to multidisciplinary. Lack of subsides and regulatory barriers also impact the technology development, and experiences from other countries show their importance. It results clear that there is a need to raise awareness regarding BIPV for everyone working with this technology. Several informants conclude that as soon as the market becomes aware of the technology and what solutions exist, there will be a huge increase of BIPV in Norway.

Q3 What role do standards play in the development of BIPV technology?
The majority of the informants have touched upon the importance of standards. The obstacles with the standards today are that they seem to be complicated and difficult to use. Several informants have pointed out the need of a simplified system that will help all the users of standards. This will also have a positive impact on the BIPV technology specifically, since it is a relatively new technology with expected growth in the years to come. Now is the time to work on revising and formulating the standards needed for the actors working on the technology. Standards are highly important for a technology adoption, and the availability has to be improved to make it easier for the users of standards.

Today the major obstacles slowing down the development seem not to be about the technology itself, but about all the framework conditions, agreements and dialogues with the authorities. There is a huge gap in the visions people have for climate and power development, in relation to what is done in reality and what happens in regulations. BIPV is considered a conflict-free way of combining the development of power and the use of existing buildings and infrastructure. BIPV therefore seems like a promising solution to help facing the climate challenges in the years to come.

Estonia appears to have solved many challenges Norway is now working on to overcome. Estonia has received good subsidies schemes for solar cells in general. The country implemented the right tools to be able to examine and acquire knowledge within this sector as a whole. It has been easier to increase the awareness and market share of solar cells and specifically BIPV because they have the economic framework in place. The support schemes have made it easier to offer these solutions making BIPV more advantageous to install than in Norway.

This study shows the importance of good standards. Insights from the actors in the sectors pointed out what has to be done in the future to improve this situation. Standards are likely to play a major role in the development of new technologies and ensure access to the solar energy market.

6.1 Future Work

Previous studies present how an outbreak of fire can affect solar cell installations, but due to relatively few solar cell installations in Norway, there is not much data yet. It is clear this is a topic that should be further researched as solar cell installations are expected to increase significantly in the coming years.

The fact that BIPV falls between two areas of expertise has made it difficult for the actors working with this technology. There should be more research and work to clarify guidelines on how to make the conditions easier for BIPV technology to evolve and to develop the standards needed.

It would have been interesting to investigate the costs of BIPV. It would have been an idea to look at already existing BIPV facilities and do calculations looking at the performance compared to what it is expected to produce. Costs seem to be a barrier for the technology to evolve and a study like this could be very valuable for the actors working with the technology as well as customers.

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A Appendix: Interview guide experts, suppliers/installers, architects and builders

Introduction:

- Tell briefly about the purpose of the thesis.
- Inform about how the data material is to be processed during and after the interview.
- Inform about the subject's right to cancel the interview if desired.

Questions:

1. What are your experiences working with BIPV?
2. What is important to consider during planning and engineering of a BIPV project?
3. What is different with the design process of BIPV compared to a BAPV installation?
4. Was is difficult to start up a BIPV project?
5. How did you start and what did you wish you knew when you started?
6. Describe some challenges you encountered, and how did you overcome them?
7. What are the main technical challenges with BIPV?
8. What do you think about the costs of BIPV?
9. Do you think that the demand for BIPV projects will increase in the future?
10. What do you think are the biggest obstacles we have today that are slowing down the development?

11. What is needed for further development?
12. What differentiates Norway's situation from the rest of the world?
13. How important are standards for establishing a growing market for BIPV?
14. Are the standards for BIPV known in the sector?
15. What is needed to make people use standards?
16. Is there anything you want to add that might be relevant to the thesis?

B Appendix: Interview guide customized questions

Experts:

1. What do you think about fire and BIPV, is this a challenge?
2. How is the ventilation behind BIPV modules?
3. How is monitoring performed on BIPV modules?
4. How will different types of inverters affect a BIPV installation?
5. How are the tools for modelling/simulating BIPV?
6. Is it difficult to repair and replace BIPV modules?

Suppliers/installers:

1. Can you start tell me a bit about your company, and why you wanted to invest in this technology?
2. What is important to take into account when installing BIPV systems?
3. What do you think about fire and BIPV, is this a challenge?
4. How is the ventilation behind BIPV modules?
5. How is monitoring performed on BIPV modules?
6. How will different types of inverters affect a BIPV installation?
7. How are the tools for modelling/simulating BIPV?
8. Is it difficult to repair and replace BIPV modules?

Architects:

1. Where there any extra expertise needed among architects to be able to integrate BIPV?
2. What does it take for architects to integrate more solar cells into the buildings that are being designed?

Builders:

1. What do you think about the environmental requirements in the years to come in the construction industry?
2. Have you used solar cells on several buildings, and are you familiar with BIPV?

C Appendix: Interview guide Estonia

1. Can you start tell me a bit about your company, and why you wanted to invest in this technology?
2. How many different products do you provide?
3. How is the market for BIPV in Estonia?
4. How are your experiences working with BIPV?
5. Describe some challenges you encountered, and how did you overcome them?
6. What are the main technical challenges with BIPV?
7. What is important to take into account when installing BIPV systems?
8. Do you think there will be an increased demand for BIPV projects in the future?
9. What do you think are the biggest obstacles we have today that are slowing down the development?
10. What is needed for further development of BIPV?
11. What do you think is different in Norway and Estonia regarding solar cells development?
12. What support schemes do you have for solar energy in Estonia?
13. Are the government in your country trying to promote renewable energy solutions, if so, how?
14. How important are standards for establishing a growing market for BIPV?
15. Are the standards for BIPV known in the sector?
16. Is there anything you want to add that might be relevant for the thesis?