Urban Insight
By Sweco

Solar Energy Resilience

Emergency power from solar panels during blackouts

SWECO

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Introduction and summary of insights

Assuming that electricity resilience can be enhanced through residential solar energy and emergency inverters, an analysis of possible electricity resilience in nine European countries over the next five years shows that the Netherlands has the best potential, whilst countries in Northern Europe are the least prepared.

Energy resilience and power outages
Concepts such as resilience, energy security and energy independence have come into focus during the last couple of years in Europe due to an increasing number of incidences of extreme weather, further fuelled by external threats such as Russia's invasion of Ukraine in 2022 and the resulting energy crisis. Citizens and authorities might need ways to mitigate possible prolonged power outages, which disturb basic societal services.

Emergency power from solar panels
In the event of blackouts, several basic societal needs might be maintained by emergency power from household solar panels combined with so-called emergency or hybrid inverters. For example, mobile communication between citizens and authorities and access to water. Other basic needs are cooling, storing and cooking food, and heat.

Solar-panel inverters
A standard grid-connected, solar-energy plant will stop producing electricity during a power outage. This is mainly due to safety reasons, as continued production would route electricity back to the grid, creating a danger for maintenance personnel. It is the inverter that stops production because, in its simplest form, it needs the grid's frequency to synchronise to. Therefore, to be used for emergency power, residential solar panels need to be equipped with the right type of inverters.

Emergency and hybrid inverters
Inverter solutions that can regulate a smaller load during a power outage without requiring batteries are called emergency inverters. An emergency inverter can regulate loads ranging from 1.5-3 kW, which allows for the operation of essential appliances such as phones, lights, radios and refrigerators during power outages, during day time when the sun is up. A solar-energy system could also provide electricity with a hybrid inverter or with connected batteries or other type of storage unit. These hybrid inverters are, however, much more expensive than emergency inverters.

Solar-power capacity
The ongoing energy transition, decreasing solar prices, subsidies and the implementation of increased regulations are all drivers of solar-power systems across the countries examined in this report. These developments signify a significant shift towards sustainable and resilient energy sources. Solar-power capacity varies among the countries analysed, with Germany leading in installed capacity and the Netherlands having the highest capacity per capita. Norway currently has the lowest spread of solar power, far behind the top countries. Sweden is also at the lower end, as is Finland.

Energy resilience potential for households
Looking ahead five years, the study highlights the potential for achieving resilience through residential solar energy and emergency inverters. If all residential solar-energy installations from 2023 to 2028 incorporate emergency inverters, it could result in 8% of each country's population having resilience during power outages.

Emergency power for neighbours
If households can provide electricity for three neighbouring households, the resilience coverage could be extended to 33% of the population. The Netherlands stands out with the highest potential to achieve resilience, potentially covering almost 100% of its population.

Energy resilience for critical infrastructure
There is also a theoretical potential to enhance resilience in critical infrastructure, such as water management and mobile communications, by integrating solar-energy solutions or situating them near solar-power plants. Overcoming various challenges, including technological integration, infrastructure compatibility and regulatory considerations is key to realising the full benefits and ensuring the robustness of critical infrastructure resilience.

Conclusions
To conclude, integrating emergency inverters into residential solar-energy systems shows promising potential for achieving electricity resilience during power outages. By implementing emergency inverters and addressing associated costs, load coverage and critical infrastructure needs, countries can enhance their ability to provide essential services and improve the overall resilience of their electricity supply.

Aim and scope of study

The aim is to examine the potential to achieve electricity resilience in the next five years by using an emergency inverter. The study covers an analysis of how residential solar power can contribute to electricity resilience in the case of a power outage in nine European countries.

Sweco analysed current and future installed solar-energy capacities and trends, as well as available support schemes for new solar installations in all nine countries. With regards to the potential level of resilience likely to be achieved by 2028, the future development of solar energy has been examined through three different case studies.

Furthermore, a cost analysis comparing the costs of normal, hybrid and emergency inverters has been performed in order to get a clearer view of how much greater resilience is likely to cost. Lastly, Sweco has analysed the potential load that could be covered by an emergency inverter, as well as how much electricity can be supplied by residential solar systems in each country.

Although the study mainly focuses on residential solar energy, a central aspect to consider is whether and how this could be applied on a societal level. Sweco has, therefore, analysed the potential for applying the same principal to some areas of critical infrastructure such as mobile communications and water-management systems.

Several assumptions have been made due to differences in data granularity in different countries. The assumptions are set out in Appendix A and on the relevant pages of this report.

Figure 1. Countries that have been included in the study

Understanding power outages

As this study examines the level of electricity resilience that could be achieved during a power outage, the following sections aim to give a clearer understanding of what happens in society and to a solar-energy system during a power outage.

A power outage can be caused by a number of different occurrences and might last for different lengths of time. Longer power outages are usually caused by storms or other extreme weather events, for instance, heavy snowfall or lightning. The electricity grid is also a vulnerable target for external threats, as a power outage affects the whole of society. Both current and future changes to the environmental and political climate might lead to increased power outages, a reality which has increased general awareness of electricity resilience as an issue.

The severity of the effects from a power outage might vary depending on how long it continues. During longer power outages, the day-to-day life of citizens might be greatly affected due to heavy dependence on electricity. The effect on a societal level includes water and heating systems being disrupted, as well as public transport, banks etc. being shut down. Although some functions of societal importance might have back-up power for a limited time, a power outage could continue for a longer period. For the average citizen, fundamental needs such as access to water, food, heating and/or cooling and communication might become unavailable for some time.[1]

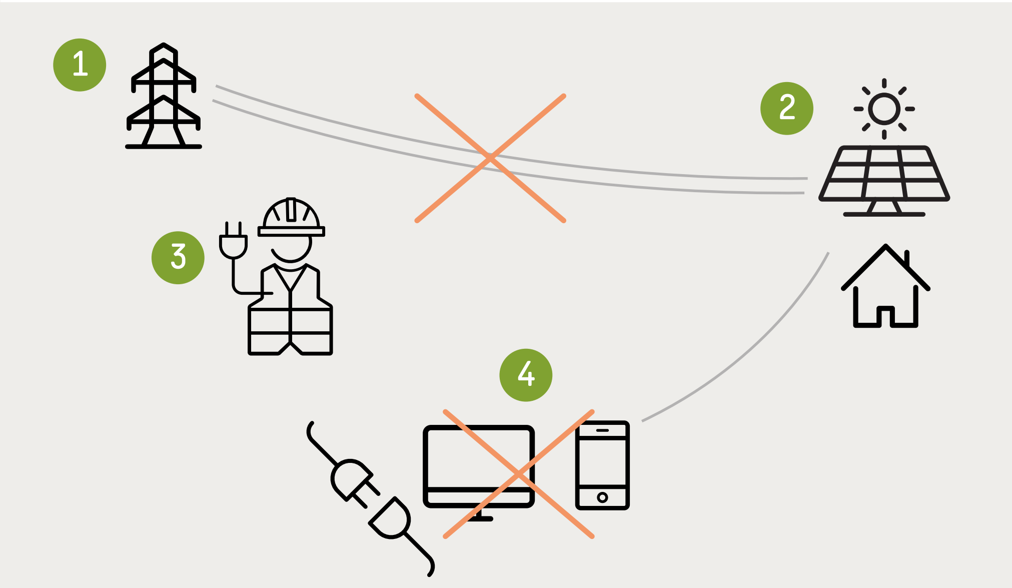
Resilience of grid-connected solar systems in power blackouts

In the event of a power outage, a standard solar-energy system stops producing electricity to prevent the power being fed back into the grid. However, an emergency inverter can operate in an 'island mode', where electricity is no longer supplied to the grid but production is continued locally, to a household for instance. Currently, emergency inverters mainly cover smaller loads and function for small-scale solar-power production, hence the study focuses on residential solar energy.

Figure 2. Overview of how a solar-energy system operates during an outage with a normal and an emergency inverter.[2]

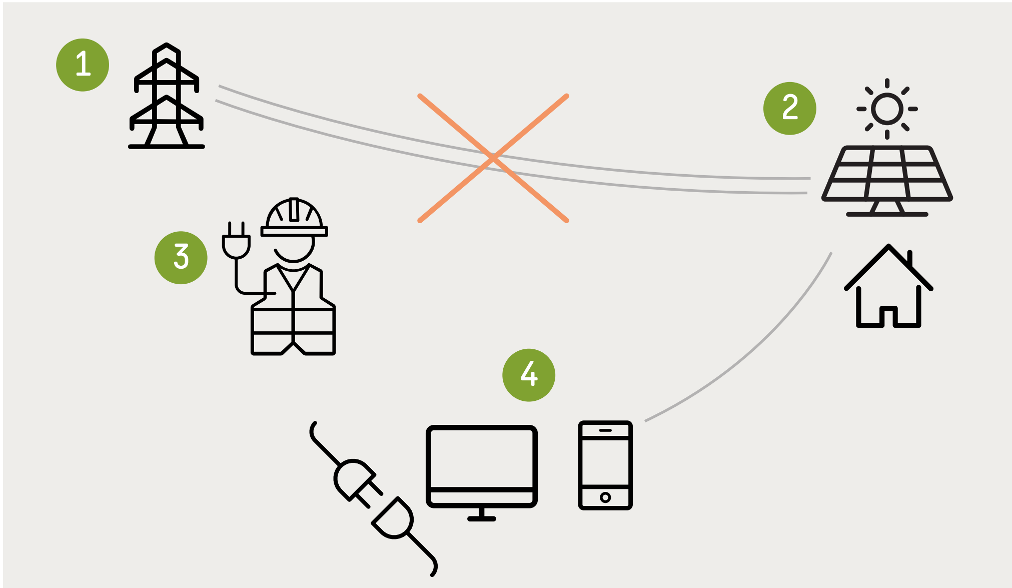
With normal inverter
During a power outage, the inverter cuts off solar-power production to prevent electricity being fed into the grid. This is due to the safety aspects of potential grid maintenance.

1) Power outage in grid.
2) Inverter cuts off solar power production to prevent electricity to being into the grid. This is due to safety aspects of potential grid maintence.
3) With the solar system being shut down, safe maintenance of grid can be performed.
4) However, there is no electricity supplied to the household.



With emergency inverter
During a power outage, the emergency inverter switches off electricity that is supplied to the grid, which enables safe maintenance to be performed. However, power supplied to the household can continue, leading to continued electricity access, as long as the sun is shining.

1) Power outage in grid.
2) Emergency inverter switches to safe solar-power production and electricity supplied to the grid is cut off.
3) With no electricity fed into the grid, safe maintenance of the grid can be performed.
4) Electricity can continue to be produced to supply the household as long as the sun is shining.



Solar energy today

Insights into a varied European landscape

In recent years, solar energy has increased rapidly in European countries reaching a cumulative installed capacity of 119 GWp at the end of 2022. Currently, the average solar-energy capacity per capita in all countries is around 0.55 kWp/capita.

Germany has the highest solar energy capacity of all countries

Sweco has compiled and analysed data relating to current solar-energy capacities and distribution, as well as historical development for all nine countries included in the study. The data is presented in Table 1, in which the countries have been ranked from highest to lowest (1–9) based on total installed solar-energy capacity.

The cumulative solar-energy capacity in all countries was around 119 GWp by the end 2022. Germany has by far the largest installed solar-energy capacity with around 67 GWp[3], which is more than the rest of the countries together. Germany is, however, also the largest country with regards to population. Norway has the lowest installed solar-energy capacity at around 0.3 GWp.[4]

If instead we look at installed capacity per capita, the Netherlands is ranked the highest amongst the countries with 1.07 kWp/capita[5], while Norway is far below the average at 0.06 kWp/capita. Finland is also at the lower end of installed capacity. However, Finland has the largest share of residential solar energy[6], closely followed by Belgium[7].

Sweden has experienced the largest average growth per year during the past five years with a CAGR of 59 %[8]. Although the CAGR for 2017–2022 is lower for some countries, all countries experienced a significant increase in installed solar energy in 2022 compared to 2021.

Table 1. Overview of solar energy in all countries.[9]

#	Country	Total installed solar-energy capacity 2022* (MWp)	Average yearly growth (CAGR) 2017-2022	Share of residential solar energy (%)	Population 2022 (millions)[10]	kWp/capita 2022
1	Germany	67,399	10%	16%	83.2	0.81
2	The Netherlands	18,800	45%	40%	17.6	1.07
3	The UK	14,658	3%	27%	67.5	0.24
4	Belgium	7,741	15%	65%	11.6	0.67
5	Denmark	3,093	22%	19%	5.8	0.53
6	Sweden	2,648	59%	57%	10.4	0.25
7	The Czech Republic	2,463	4%	18%	10.5	0.23
8	Finland	667	54%	75%	5.5	0.12
9	Norway	336	51%	40%	5.4	0.06
	Total countries	**119,434**	**12%**	**26%**	**217.8**	**0.55**

Support schemes available in all countries

In all of the nine countries included in this study, various types of support schemes are available for solar installations. In Sweden, Germany, Finland and the Czech Republic different types of subsidies or tax deductions are available for battery installations as well.

Solar installation support varies significantly depending on the country

Although solar installation schemes are available in all countries included in the study, they are designed differently. Common forms of support are subsidies, credits and/or tax deductions. Furthermore, support schemes can vary between different regions/federal states, as in Belgium and Germany, for instance. Support schemes for battery installations are only found in Sweden, Germany, Finland and the Czech Republic, although there have been suggestions that a nationwide funding scheme for batteries might be established in Norway as well.[11] Details relating to the different schemes available on a country-by-country basis are given in Appendixes B and C.

In some countries, upcoming changes to support schemes are planned. In the Netherlands, there will be a change in legislation, probably after 2025, which will end a very favourable scheme for small houses by 2031. In Belgium, the current premiums provided in the Flanders region have been halved as of March 2023. Furthermore, current subsidies for low-income households in the UK will end in 2027. Denmark previously had a scheme for selling and buying solar energy to and from the grid. Currently only a small tax deduction exists.[12]

Subsidies, tax deductions, legislation and other schemes have been shown to be a driving factor behind residential solar-energy development. This has mainly been observed in the Netherlands, Belgium and Norway. In Belgium, supportive governmental policies together with decreasing prices are the main driving factors behind recent increases in the use of solar energy. Likewise, similar factors have driven development in Norway. In the Netherlands, a very favourable scheme has resulted in a significant increase in the use of solar energy in the residential sector and the change to the legislation is expected to influence that development.

No requirements for emergency power in European countries

Table 2. Solar and battery support schemes in all countries examined.

Country	Type of support solar	Type of support batteries	Outlook[13]	Requirement emergency power
Sweden	Tax deduction	Tax deduction		X
Belgium	Premiums	-		X
Germany	Subsidies, credits, loans	Subsidies, credits, loans		X
Norway	Subsidies	-		X
Finland	Tax credits, subsidies	Tax credits, subsidies		X
Denmark	Tax deductions	-		X
The Czech Republic	Subsidies	Subsidies		X
The Netherlands	Subsidies, tax deductions	-		X
The United Kingdom	Subsidies, VAT deductions	-		X

None of the countries included in this study have any requirements for emergency power functionality. As there is extensive support for solar energy in all these countries, a higher degree of resilience might have been achieved if this aspect had been considered. This, however, also requires that there is a market for the technology of emergency inverters. An overview of support schemes is presented in Table 2.

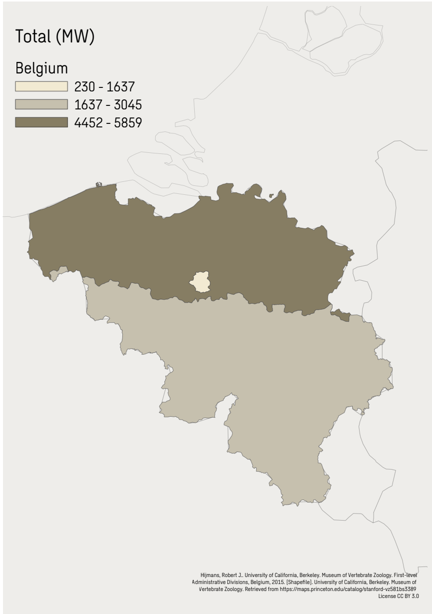
Regional spread of solar energy varies

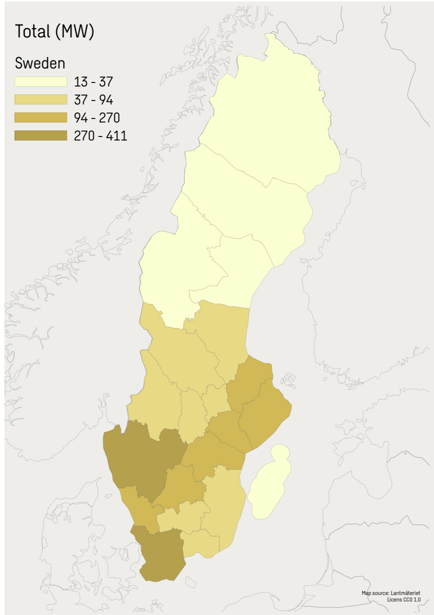
The figures to the right represent the regional spread of solar energy in Belgium, Sweden, the Czech Republic, Germany and the UK. Solar energy is mostly found in the northern parts of Belgium (Flanders region), this might, however, be related to more extensive support for solar energy in this region, as well as it being a more populous and economically developed region.

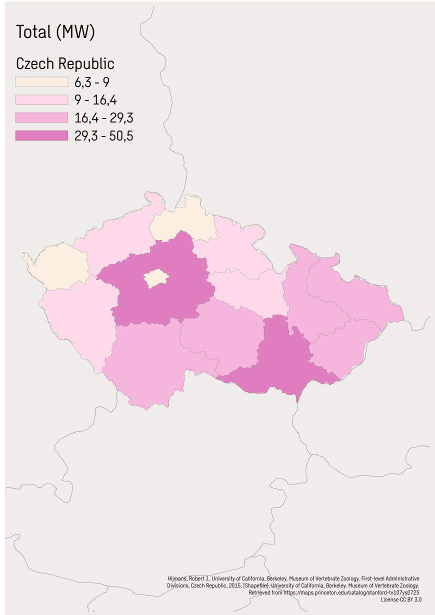
In Sweden, solar energy is mostly found in the southern and western regions, which is reasonable due to the higher levels of solar radiation. In the Czech Republic, solar power is more common in the southern parts of the country, as well as in the areas surrounding the capital Prague. In Germany, the south-east region has the most installed solar-energy capacity, which differs significantly from the rest of the country with capacities from 8-19 GWp compared to 0.07-0.7 GWp in other regions. In the UK, the south-east and west coast have the most installed capacities.

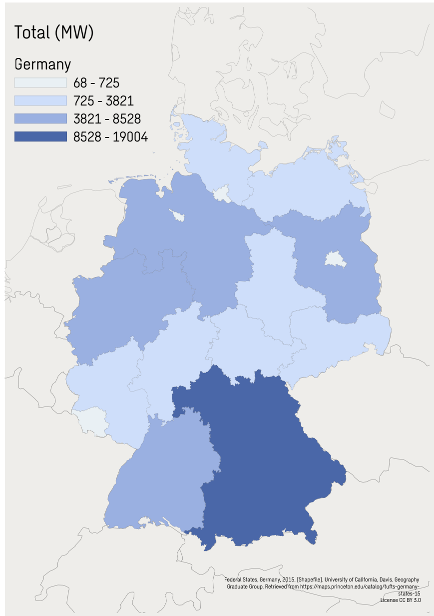
Capitals of the respective countries generally have a significantly lower level of installed solar-energy capacity. High densities of households as well as high numbers of multi-family houses are usually more common in larger cities, which might be one reason for the lower levels of solar power. As capitals are usually home to a large proportion of the population, it is important that we further investigate the conditions and potential solutions for achieving greater resilience for multi-family houses.

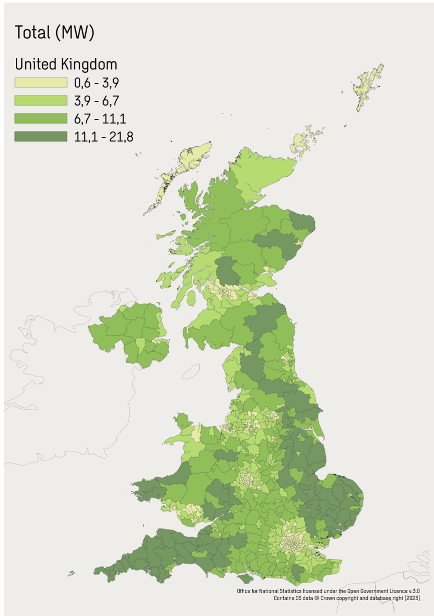
Regional spread of solar energy











Regional spread of solar energy in Belgium, Sweden, Czech Republic, Germany and the UK.

Summary of solar energy across countries

Belgium

Belgium has experienced a rapid increase in the total installed solar-energy power as a result of supportive government policies and the decreasing cost of solar installation.

The majority of new solar-energy power installations are smaller residential and commercial setups. However, community solar projects are slowly gaining momentum due to complex and unhelpful legislation. As the use of solar power is intermittent and seasonal, there is a growing importance placed on smart grid technologies, energy storage solutions and demand-side management.

Most solar installations (65%) in the country are small-scale, typically installed on residential rooftops. Residential solar energy has grown between 400-500 MW/year. Flanders, being the most populous and economically developed region, accounts for most of the total installed solar-energy capacity. Namely, 76% of solar-energy capacity is found in Flanders region, while 21% is found in Wallonia and 3% in Brussels.[15] Each region has different legislation but follows more or less the same installation trends for solar-energy installations.

The Czech Republic

The Czech Republic had a total solar-energy capacity of 2.5 GWp in 2022. Although quite a modest growth has been observed in the past five years, the increased capacity difference between 2021 and 2022 was significant, mainly in the residential sector. In 2022, a total of 33,760 solar-energy plants were installed compared to 9,354 plants in 2021. 98% of this new capacity were residential plants, which made up 18% of total solar-energy capacity in 2022.[16]

The growth in demand for residential solar-power plant installations in 2022 has increased by 262.2% compared to 2021.

The dramatic increase in energy prices resulting from the Russian aggression in Ukraine is the reason for the huge increase in demand for photovoltaic power plants. Demand is also being boosted by the interest in moving away from energy dependence on Russia and fulfilling the Paris Agreement climate goals.

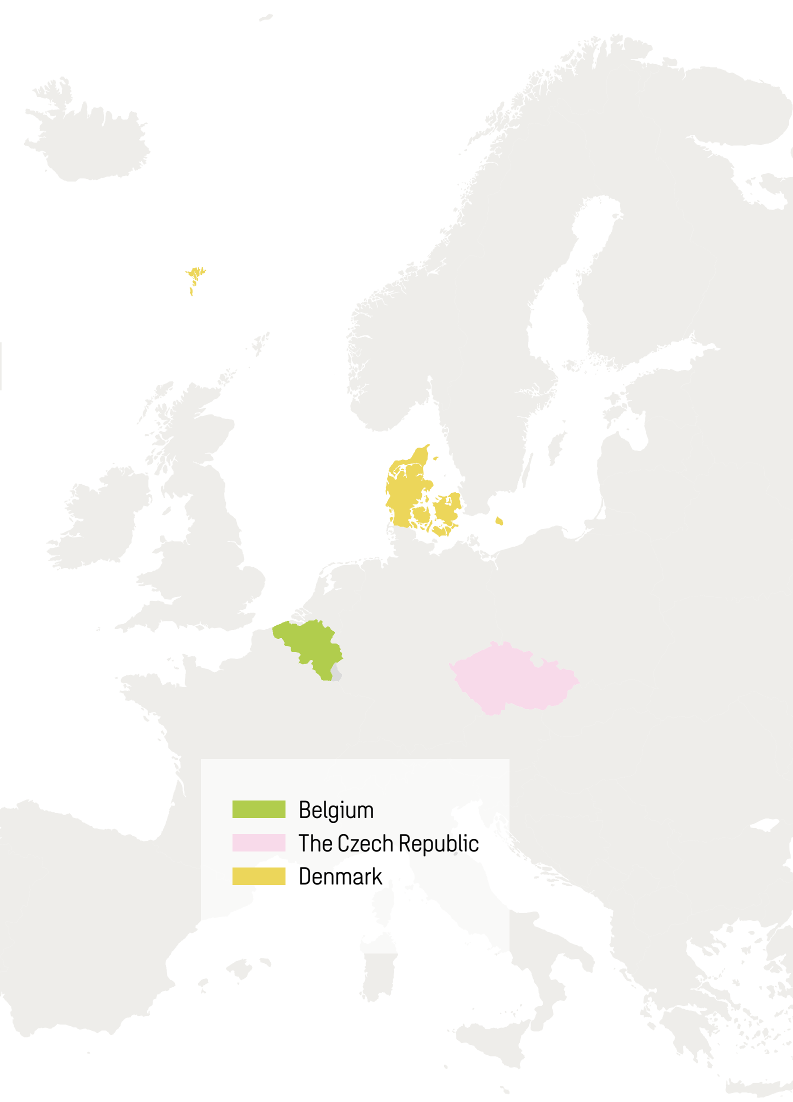
Denmark

As of 1 January 2023, the installed capacity of solar energy in Denmark is approximately 3 GWp. Residential solar energy accounts for around 19% of the total installed capacity in Denmark, while large solar parks of 1 MW and greater make up around 70%.

During the past five years, installed solar energy in Denmark has doubled, with an average yearly increase (CAGR) of around 20%.

In comparison to other countries in this study, Denmark is currently in the middle range for total installed solar-energy capacity, as well as installed capacity per capita (0.53 kWp/capita).[17]

Residential solar-energy installations are more widely distributed outside of the large cities, as there are many apartment blocks in larger cities where solar energy is not installed. Hence, the Greater Copenhagen area has the lowest number of solar-energy installations despite this being the region with the most households. In particular, west- and southern Zealand and Jutland have many household solar-energy installations.[18]



Summary of solar energy in all studied countries cont.

Finland

In 2022, Finland had around 0.6 GWp installed solar-energy capacity.[19] Compared to other countries in the study, Finland is currently also at the lower end for the level of installed solar-energy capacity. The development of solar energy has, however, increased rapidly in the past five years, with a CAGR of more than 50%.[20] However, the installed solar energy per capita is amongst the lowest at 0.12 kWp/capita.

The residential sector accounts for around 75% of the total solar-energy capacity, which implies that residential solar energy is the most common and familiar form of solar energy in Finland.

Finland also has a large share of off-grid connected systems; however, these have not been included in this study. In recent times, industrial and large-scale solar energy has begun to develop more.[21]

Germany

As of 2022, Germany had the largest share of installed solar-energy capacity amongst the countries studied in this report with a capacity of over 67 GWp. Residential solar energy accounts for around 16% of total installations. In the past five years, Germany has experienced a quite modest growth with a CAGR of 10% and an increase from 42 GWp to 67 GWp. However, 7 GWp was installed between 2021 and 2022, which is a significant share compared to other countries.[22]

Looking at installed solar-energy capacity per capita, Germany is in second place with 0.81 kWp/capita, just after the Netherlands. The largest share of solar energy is found in the southern regions, where the Bayern region has the largest share.

More than 20% of households in the southern regions are covered by solar energy, while the proportion in the middle and northern parts of Germany ranges between 0–15%.[23]

The Netherlands

The Netherlands had a total installed solar-energy capacity of almost 19 GWp in 2022, making it the country with the second largest installed solar-energy capacity amongst the countries. The Netherlands has the largest installed capacity per capita with more than 1 kWp/capita. In the last five years, solar-energy capacity has increased by a factor of 6.5, from 2,9 GWp to almost 19 GWp.[24]

The residential sector makes up around 40% of the installed capacity. This accounts for more than two million households, which means that 25% of Dutch households are covered by solar energy.

Furthermore, residential solar energy is quite evenly distributed throughout the Netherlands. There are, however, some differences depending on the type of building. In densely built cities and/or city centres, the percentage of houses with solar energy is lower, and in suburbs and villages, the percentage is higher.

Summary of solar energy in all studied countries cont.

Norway

Although Norway has the lowest amount of total installed solar-energy capacity amongst the countries, and despite its reputation for cloudy weather, Norway has seen a significant increase in solar-energy installations in recent years. As of the end of 2022, there were approximately 19,000 solar-power installations across the country, with a total installed capacity of around 0.4 GWp. The residential sector accounts for 40%.[25]

This represents a substantial growth in solar-energy capacity compared to a decade ago, when Norway had only around 0.030 GWp of installed solar capacity.

The growth of solar energy in Norway can be attributed to a number of factors including falling costs and increasing demand from businesses and households, as well as government policies aimed at promoting the adoption of renewable energy. The highest rate of development has been in the south-east of Norway.

Sweden

The installed solar-energy capacity in Sweden was around 2.6 GWp in 2022. Sweden is at the lower end of both the installed solar-energy capacity and capacity per capital in comparison to the other countries in the study. In 2022, the installed capacity per capita was around 0.25 kWp/capita. Furthermore, solar-energy capacity is quite unevenly distributed in Sweden, with the largest proportion of solar-energy capacity located around the capital Stockholm, the south and the mid-western regions. The residential sector accounts for around 57% of the installed capacity in the country. [26]

During the last five years, Sweden has experienced a quite significant growth in the solar-energy section, with 10 times the installed capacity in 2022 compared to 2017.

The residential sector as well as utility scale solar energy accounts for the largest share of this growth.[27]

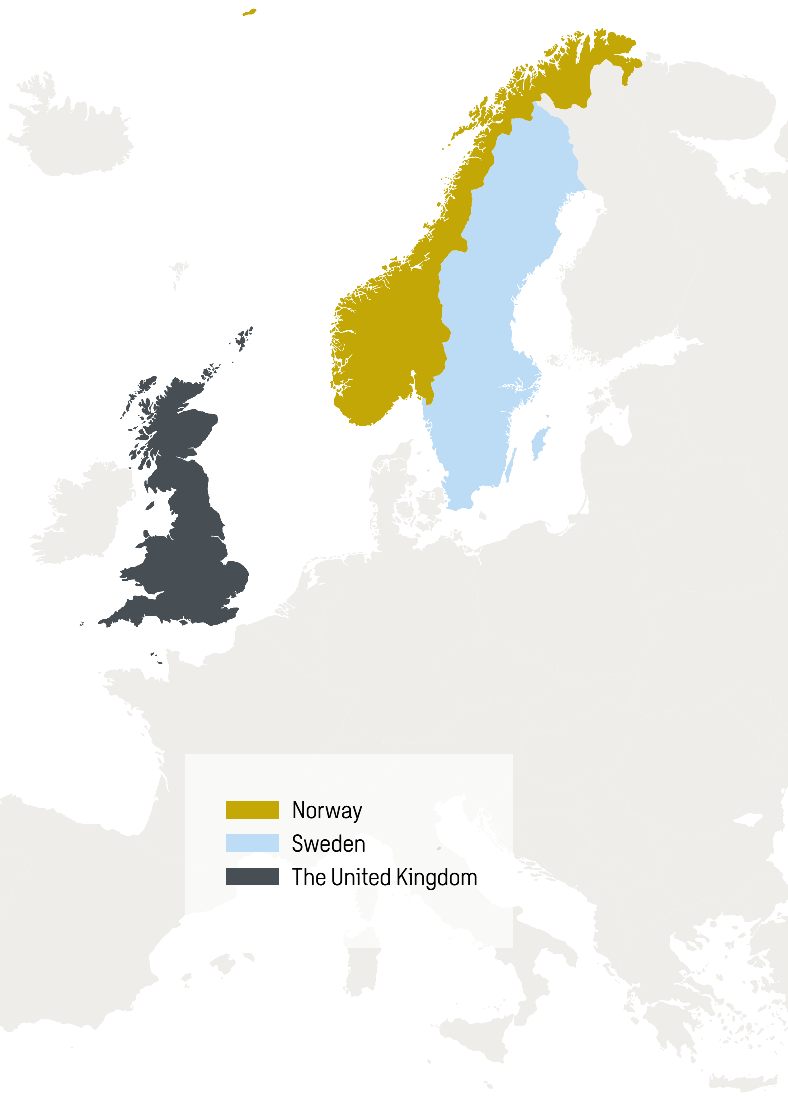
Swedish tax legislation on self-consumed electricity for plants > 500 kW makes it harder for commercial (medium-scale) solar energy to be economically viable.

The United Kingdom

In 2022, the total installed solar capacity in the UK was around 16.2 GWp.[28] Around 4.4 GWp of the capacity was recorded as being located on domestic properties. This means that 27% of the total solar-energy capacity generated is from domestic residential properties.

There are roughly 1.2 million UK homes with solar panel installations, which means that 4.1% of the 29 million homes in the UK are generating electricity from solar-panel installations.[29]

In the last five years, UK installed PV capacity has increased by around 2 GW, which corresponds to an average yearly growth rate of 3%. Although this might seem low compared to the other countries in the study, there is currently a high demand for solar-energy installations in the UK and grid owners are swamped. Compared to the other countries, the UK is at the higher end of the scale with regards to total installed solar capacity.



Future solar energy

An outlook on solar energy development

During the next five years (2023–2028), the cumulative residential solar-energy capacity is expected to increase by around 40.4 GWp in all countries. This would correspond to around 7.7 million new households with solar-energy capacity.

Development drivers include the energy transition, subsidies and legislation

Sweco has studied the future development of residential solar energy in the respective countries including installed capacity, number of households and future kWp/capita. All of these countries are expecting an increase in residential PV, though to varying extents. In Table 3, the countries are ranked from 1-9 based on installed capacity per capita by 2028.

For all countries, the number of households with solar energy will grow significantly between 2023-2028. In comparison to the number of households with solar energy in 2022, this corresponds to an increase of around 100% for Sweden, while the Czech Republic, Belgium, the Netherlands and Denmark will see a slightly lower increase. On the other hand, Germany, the UK, Norway and Finland are expected to see an increase of between 150–350% of households compared to the number of solar households in 2022.

The energy transition and climate targets are two of the driving forces behind the development of solar energy going forward, as more people focus on sustainable solutions. Technology development as well as the integration of technical solutions such as vehicle-to-grid (V2G) charging and building integrated solar panels will also offer residential solar energy owners greater opportunities. Subsidies and increased awareness of energy independence have also been identified as important drivers behind the increase. Further more, legislation might also have an effect, for instance, in the UK and parts of Germany, where solar energy or corresponding energy systems are mandatory for new household construction.

Table 3. Overview of the estimated development of residential solar energy in all countries

#	Country	Capacity increase 2023-2028[30] (MWp)	Additional number of households 2023-2028	Average solar system size (kWp)	Average yearly growth (CAGR) 2023-2028	Population 2028[31] (millions)	kWp/capita 2028
1	The Netherlands	6,733	1,794,079	3.8	12%	18.2	0.88
2	Belgium	2,444	561,591	4.4	7%	11.9	0.69
3	Germany	20,884	2,983,378	7.0	18%	85.3	0.44
4	Finland	1,276	255,119	5.0	20%	5.6	0.37
5	Sweden	1,441	126,348	11.4	13%	10.9	0.30
6	The UK	6,453	1,778,570	3.6	16%	68.8	0.18
7	Denmark	290	54,238	5.3	7%	6.0	0.16
8	Norway	441	50,128	8.8	31%	5.6	0.11
9	The Czech Republic	456	52,991	8.6	13%	10.9	0.10
	Total	**40,417**	**7,656,443**	**6.4**	**15%**	**223.3**	**0.37**

Summary of future development across countries

Belgium

The use of solar power has increased rapidly in Belgium. Legislation has been shown to be a significant driving factor for this development.

Belgium will have the second highest installed residential solar capacity per capita by 2028[32].

In the country, there is an increased focus on building integrated photovoltaics and building-attached photovoltaics combined with facade isolation and design. New technologies allow for greater opportunities for residential solar-energy owners and could be viewed as driver for this development.

Although new technologies like locally printed 3D panels based on perovskite technology have yet to enter the Belgian market, they offer tremendous opportunities for architects, for example, for use in solar car parks. Furthermore, technologies like vehicle-to-grid (V2G) are slowly being adopted, which also could drive the development of increased installed residential PV.

The Czech Republic

The Czech Republic has experienced a significant increase in demand for residential solar energy in 2022, mainly as a result of Russia's invasion of Ukraine and increased demand for energy independence. This, together with the Paris Agreement climate goals, is expected to continue to drive the development of solar energy in the country. Furthermore, a change of legislation removing the requirement for building permits for facilities up to 50 kWp (raised from 10 kWp) will facilitate the establishment of larger facilities for solar energy.

The Czech government's target is to build at least 100,000 new solar-energy plants by 2025.

According to the government's plan, the installed capacity of solar energy is to increase by 4 GWp by 2030. There are, however, some capacity shortages in the distribution network, which, in some cases, might hinder the sale of overflow solar-energy electricity to the distribution network. The distribution network is being strengthened, but the development is not as rapid as the construction of new solar-energy plants.

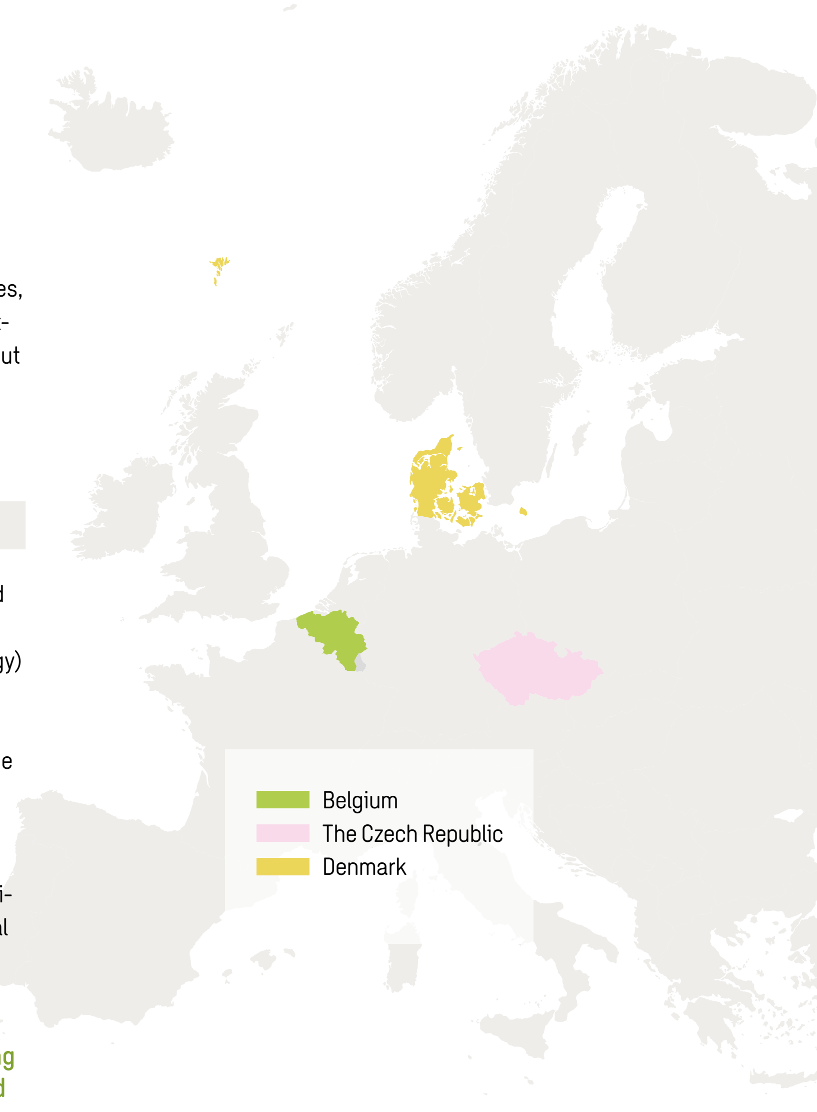
Denmark

Although Denmark is currently in the mid-range for current installed solar-energy capacity, the targets for installed roof-top capacity going forward (including both small- and medium-scale solar energy) are ambitious. According to the Danish Energy Agency's study 'Denmark's Climate Status and Outlook 2023', rooftop solar plants are expected to increase by three-fold between now and 2035.[33] The Danish energy mix is expected to primarily be based on wind and solar power.

However, the development is expected to mainly concentrate on medium-scale PV, resulting in a lower development pace for the residential sector.

According to the Danish study, Denmark will have an annual growth rate of around 7% between 2023–2028, corresponding to the lowest added capacity amongst the countries of around 0.26 GWp.

The residential solar capacity per capita will be 0.15 kWp/capita, which is below the average value for the nine countries in our study.



Summary of future development across countries cont.

Finland

Finland has experienced an increase in the use of solar energy in recent years, with a large proportion being in the residential sector.

According to an estimation made by Fingrid, the installed solar capacity will reach approximately 7 GW in 2030.

The installed solar capacity is projected to increase by approximately 1 GW per year from 2024. Fingrid also estimated that half of the 7 GW capacity will be industrial-scale solar parks.

Although, historically, residential solar energy has expanded the most, the proportion of company-based, large-scale industrial projects is expected to make up a larger share of development going forward, which will create a higher growth rate in the medium- and large-scale solar energy sector.[34]

Germany

Germany has ambitious targets for installed solar-energy capacity. According to the goals set out in the Renewable Energy Sources Act (EEG 2023) for all types of solar energy-plants, 172 GW will be installed by 2028 and 215 GW by 2030. The share of large-scale solar energy, i.e ground-mounted systems, is expected to increase slightly and make up a larger share going forward.[35]

Regarding residential solar energy in Germany, around 1.5 million households are currently supplied with solar energy, and around 11.7 million one- and two-family houses are believed to be suitable for solar energy installations.[36]

In some federal states, a solar-energy system installed on the roofs of new-build residential houses is mandatory.

This is expected to be a driver for new installed residential solar energy going forward in some parts of Germany.

The Netherlands

In 2022, there was an additional 1.75 GWp of solar power installed in the residential sector in the Netherlands, a growth of 30% for total installed power. Extremely high electricity prices were the main reason for this growth.

Going forward, the additional installed power in the residential sector will level off during the next three years.

After 2025, the estimated added installed power will drop below 1.5 GWp per year. The Netherlands is at a tipping point where the growth is likely to flatten out.

The decrease of newly installed residential solar energy going forward is due to two main factors. One is that there will be a change in regulations, making it less attractive to invest in solar energy for households. The other is that most households with a suitable roof will be provided with a solar energy system by that point. Although a decreased development rate per year can be expected, the Netherlands will see a significant increase in residential solar energy compared to the other countries.

Summary of future development across countries cont.

Norway

Norway has seen a significant increase in solar energy in recent years as the number of solar-energy installations has been steadily increasing. Norway is expected to continue to see growth in the solar-energy market. According to Norway's Directorate of Water Resources and Energy (NVE), which is a part of the Ministry of Petroleum and Energy, the installed solar-energy capacity is expected to increase to around 1.8 GWp by 2030.[37]

This growth is expected to be driven by a combination of factors such as falling solar-energy costs, increasing demand and government policies, which are helping to promote the adoption of renewable energy sources.

With its commitment to sustainable energy, it is likely that solar energy will continue to play an increasingly important role in Norway's energy mix.

High electricity prices as well as more solar radiation has resulted in increased profitability in terms of produced kWh for residential solar energy. Climate targets, decreasing solar energy prices and changes in legislation, where support for installed solar energy as well as battery storage and V2G charging has been increased, can be seen as important drivers for future solar-energy development in the country.

Sweden

Similar to the other nine countries in the study, Sweden has experienced a significant increase in installed solar-energy capacity in recent years.

Residential solar energy is mainly driving the expansion of solar energy in Sweden, for which capacities doubled between 2021 and 2022.

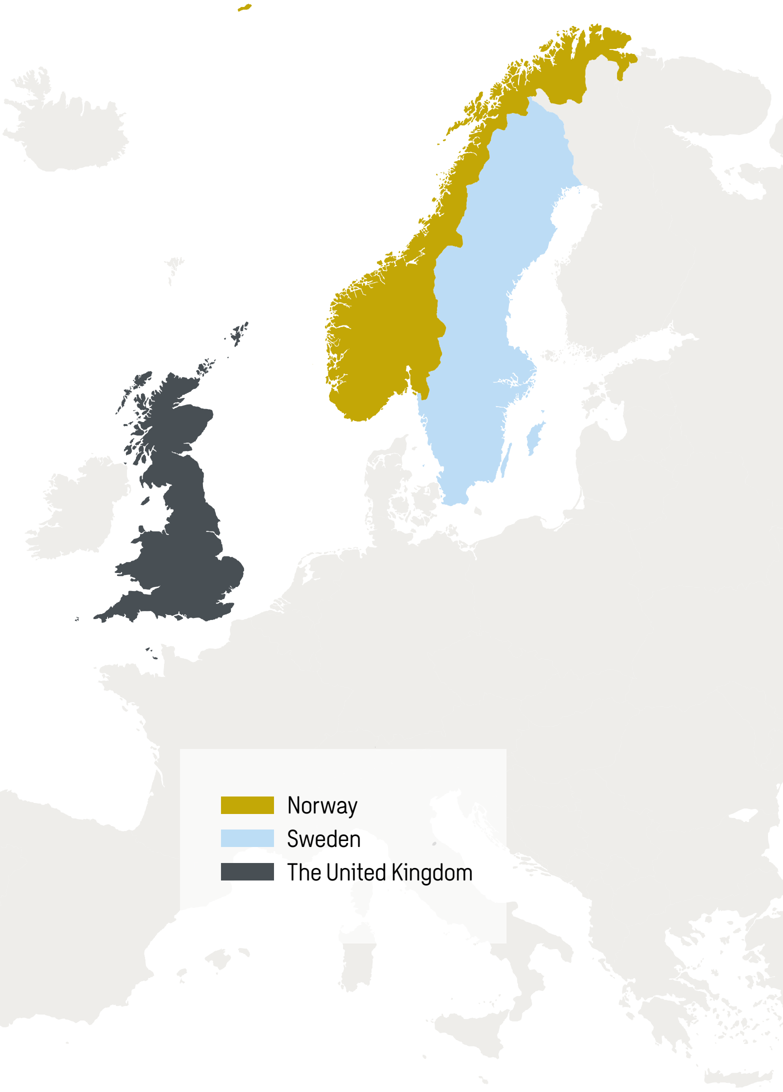
Although there are no official targets for installed solar-energy capacity in Sweden and solar-energy development generally exceeds estimated forecasts, solar energy is expected to reach more than 5 GWp in the next five years.[38]

The United Kingdom

The UK government published the Powering Up Britain: Energy Security Plan in March 2023, which sets out the steps that the government is taking to ensure that the UK is more energy independent, secure and resilient. According to the report, the government aims for a total of 70 GW from ground and rooftop capacity by 2035.[39] As part of a consultation on the Future Homes Standard to be published later in 2023, the government will explore how it can continue to drive onsite renewable electricity generation, through schemes such as rooftop solar installations in new homes and buildings.[40]

The latest data from the Microgeneration Certification Scheme (MCS), which defines and maintains the standards for small-scale domestic renewable energy and heating across the UK, demonstrates a clear indication that more households are turning towards solar to help decarbonise heating and power to their homes.

UK Building Regulations Part L for new builds, includes solar energy within the notional building and, if solar energy is not able to be used, must include alternative renewable energy sources.



Potential solar energy resilience

Sweco has analysed the potential resilience that could be achieved by residential solar energy in three different case studies. The following section presents the proportion of the population that could potentially have solar-energy resilience by 2028.

Case one: solar growth the upcoming five years

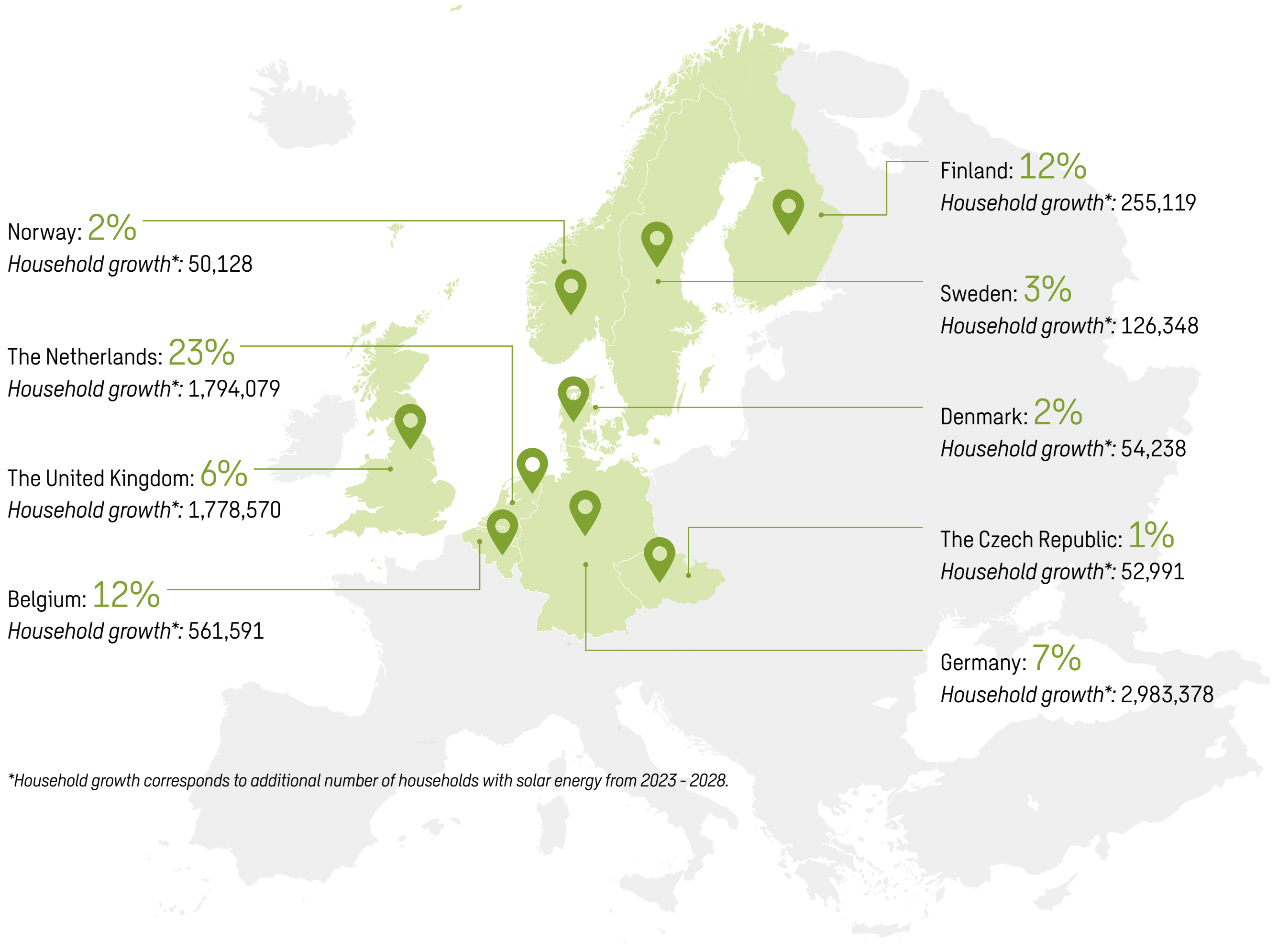
If all new residential solar-energy systems installed from 2023 also included the installation of an emergency inverter, 8% of each country's total population would have resilience during a power outage by 2028. The Netherlands has the highest potential and could cover 23% of the population.

What was studied in case one?
In case one, Sweco analysed the share of the population that would be covered by solar-energy resilience by 2028 if all new residential solar-energy installations from 2023 to 2028 also included the installation of an emergency inverter. This was done by analysing the forecasted increased solar-energy capacity and thereby the additional number of households that are likely to have solar energy equipment installed between 2023 and 2028. The number of people covered by solar energy was then calculated from the number of people living in a household. All data used for the calculations can be found in Appendix D.

Sweco's findings
The study shows that the Netherlands has the possibility of achieving resilience for 23% of the population by 2028. Furthermore, Belgium, Finland, Germany and the UK could achieve a coverage of 12%, 12%, 7% and 6% respectively. Countries that, according to the study, would cover a lower proportion of the population by 2028 are Sweden, the Czech Republic, Denmark and Norway. In total, 8% of each country's total population would have resilience by 2028 if an emergency inverter were to be installed on all new residential solar-energy installations from 2023.

The data used for the analysis includes several assumptions that could affect the results. All assumptions are presented in Appendix D. For instance, the share of residential solar energy is assumed to be the same as for 2022 for some countries. Furthermore, the level at which the estimated increased residential solar-energy capacity is set might also vary in different countries.

Figure 3. Share of the population covered by solar-energy resilience by 2028 calculated using Sweco's assumptions in case one.[41]



Case two: Providing electricity for neighbours

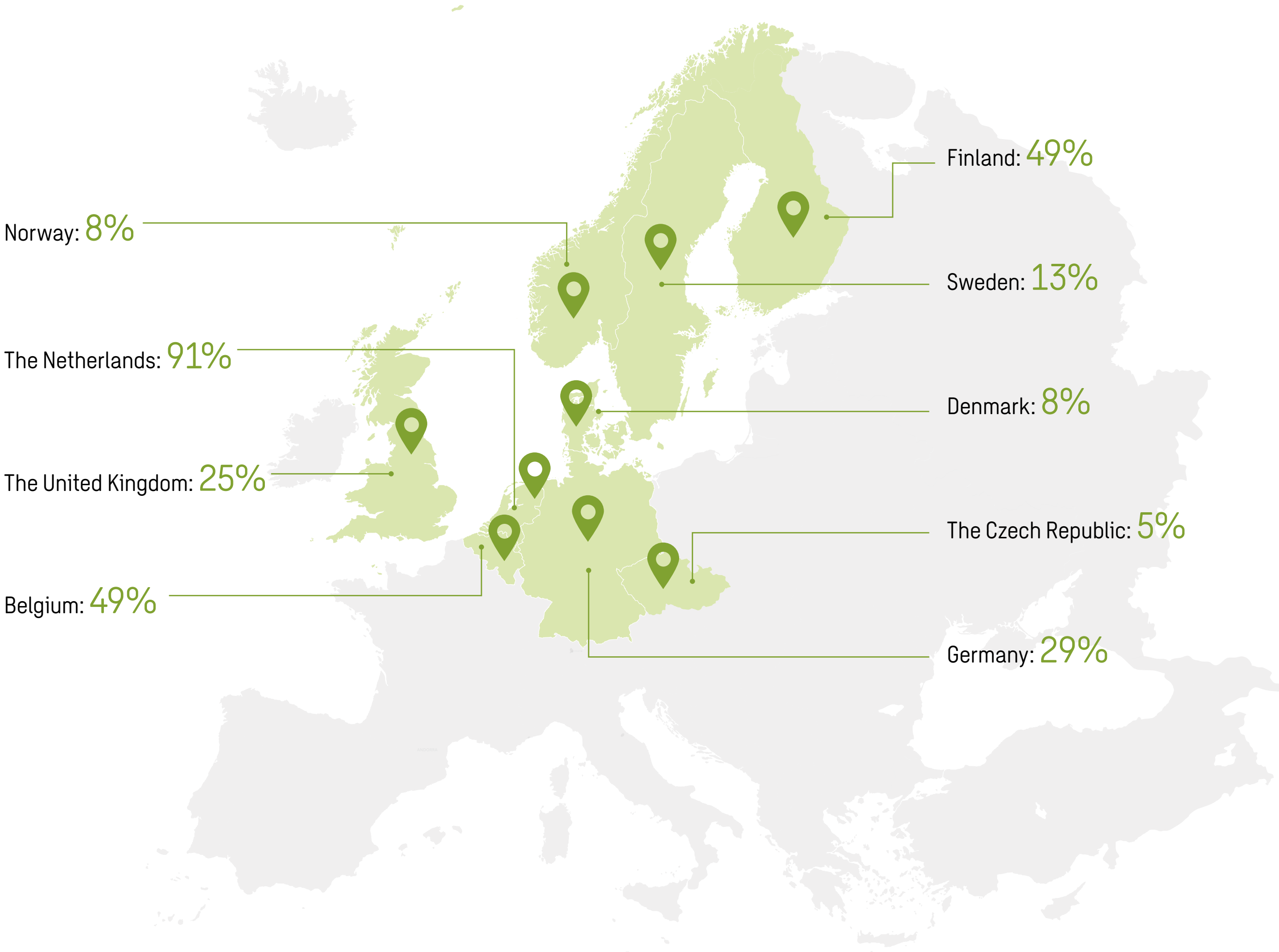
If each new solar household created up until 2028 could provide electricity for three neighbouring households during a power outage, 33% of each country's total population would have resilience. The Netherlands has the potential to cover almost 100% of its population.

What was studied in case two?
In case two, Sweco analysed the share of the population that would be covered by solar-energy resilience by 2028 if all new residential solar-energy installations from 2023 to 2028 would install an emergency inverter and if each household could provide electricity for three neighbouring households in the event of a power outage. Each household would thereby provide electricity for around 10 people. All data used for the calculations can be found in Appendix D.

Sweco's findings
The study shows that the Netherlands have the highest potential to achieve resilience. If each household could provide electricity for three neighbouring households, 91% of the population would have access to electricity. According to the data studied in case two, Belgium, as well as Finland, Germany and the UK could achieve resilience for 49%, 49%, 29% and 25% of their populations respectively by 2028. For all the countries included in the study, 33% of the population would have resilience.

However, the distribution of households and household types might vary largely within different areas of each country, as well as between different countries. Single-family houses might be located in one particular area or in the countryside, while multi-family houses could be located in another area or areas. The possibility of providing electricity for neighbours could thereby be limited by large distances between the properties. Furthermore, the electricity demand increases if multiple households are to share the electricity production from one household. Depending on the possible level of solar-power production, the maximum electricity capacity available would be around 3 kW if there is enough sunlight.

Figure 4. Share of the population covered by solar-energy resilience by 2028 calculated using Sweco's assumptions in case two



Case three: existing and future solar energy

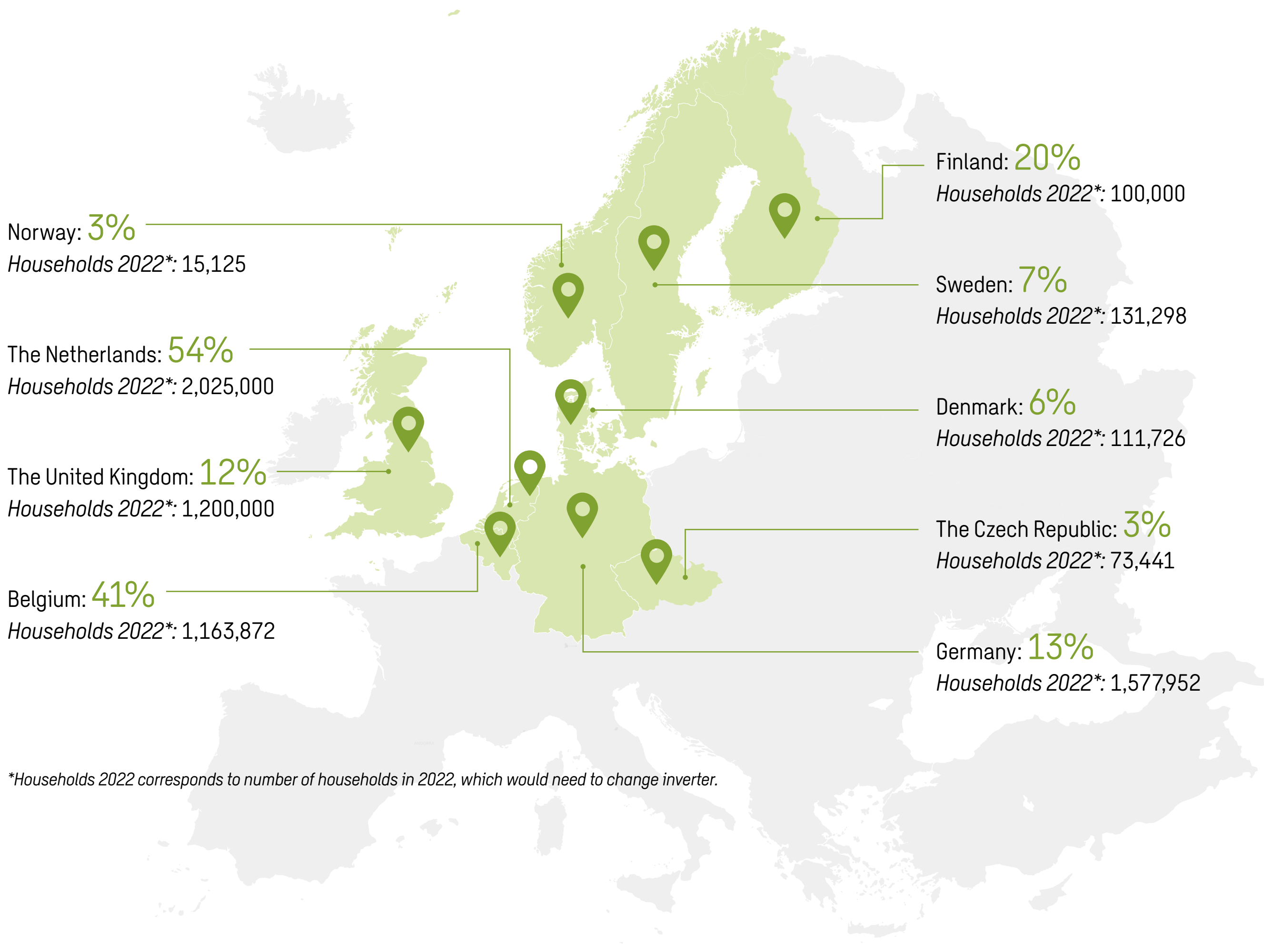
If all existing residential solar energy systems, together with the estimated number of new systems likely to be installed by 2028, also install an emergency inverter, 16% of the population in all countries could achieve resilience. The Netherlands would cover the largest share with 54% of the population.

What was studied in case three?
In case three, Sweco analysed the share of the population that would be covered by solar-energy resilience by 2028 if all existing systems, plus the new solar households that install a system between 2023 and 2028, also install an emergency inverter. This therefore implies that all households with existing solar energy systems would switch to an emergency inverter by 2028. In case three, each household provides electricity for their respective household. All data used for these calculations can be found in Appendix D.

Sweco's findings
According to the study, the Netherlands have the highest achieved resilience potential, as they could cover 54% of the population. Furthermore, Belgium has the potential to achieve resilience for 41% of the population, Finland 20%, Germany 13% and the UK 12%. For all countries included in this study, 17% of the population could have resilience if all existing and upcoming residential solar-energy systems included an emergency inverter, which is two times greater than the results seen in case one.

As an inverter has a lifetime of around 15 years, which on average is around half of the lifetime of a solar-energy module, each existing solar-energy system would need to change the inverter at least once during the lifetime of the solar-energy system. In case three, it has been assumed that all solar-energy systems would change inverter before 2028; however, this is a simplification as a large proportion of residential solar-energy capacity has been installed during the past 10 years, meaning that the remaining lifetime of most inverters exceed the next five years. The number of households with solar energy in 2022 that would need to change inverter, is presented as NH* 2022 in the figure.

Figure 5. Share of the population covered by solar-energy resilience by 2028 calculated using Sweco's assumptions case three.[42]



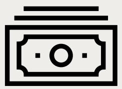
**Households 2022 corresponds to number of households in 2022, which would need to change inverter.*

The price of resilience

Higher demand brings lower prices

An emergency inverter costs around 20-40% more than a normal inverter. Prices have the potential to decrease with increased demand, as emergency inverters are currently not commonly found on the market.

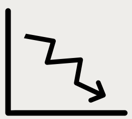
Resilience can be achieved for a 20-40% higher cost



Sweco has evaluated the price difference between normal, hybrid and emergency inverters. In Figure 6, the average total price is presented for each inverter. Prices vary depending on several factors and an average has, therefore, been calculated. Inverters of different sizes, varying between 3–15 kW have been evaluated and the prices used are from Belgium, Germany, the UK, Finland and Sweden.

20-40%

According to the study, the cost of an emergency inverter or a hybrid inverter is around 20-40% more expensive than a normal inverter. It is, nonetheless, important to highlight that prices vary significantly depending on the size of the inverter, as well as the functionality. Currently, prices might also have increased slightly due to instability in the market as well as the recession.



Given the price difference between a normal and emergency inverter, the benefit of having greater resilience in a power outage could be achieved for 20-25% higher costs, which accounts for around EUR 350-650/inverter. Historically, inverter prices have decreased by ca. 55% between 2010–2020[43] due to increased production rates (mass production). Since the emergency inverter is not commonly found on the market, prices could be expected to decrease further with increased demand. Changes in price are presented in Figure 7.

Figure 6. Average total cost (€) for a normal, hybrid and emergency inverter.[44]

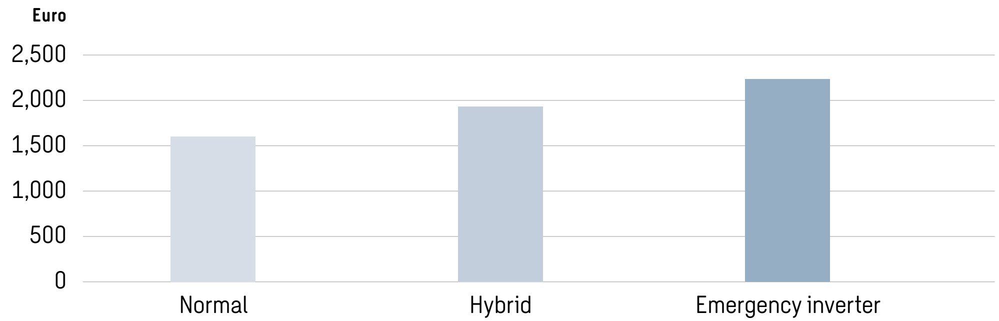
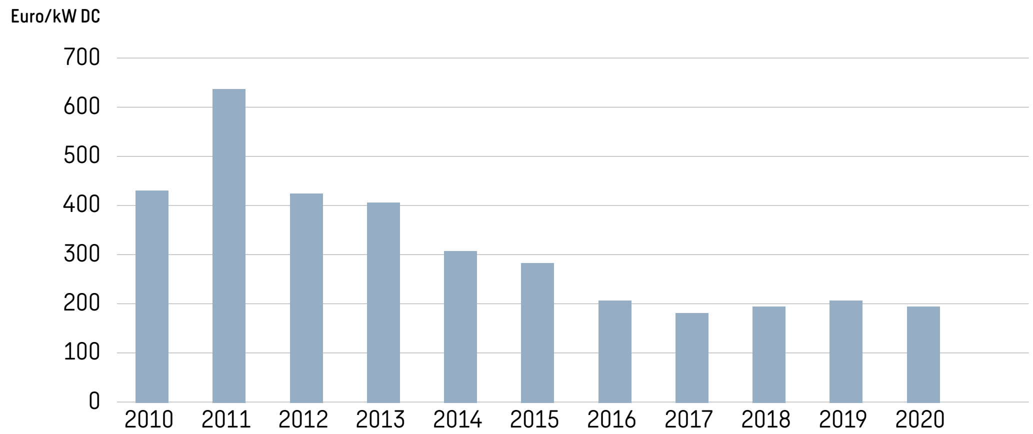


Figure 7. Historical development of inverter costs €/kWDC from 2010-2020.[45]



Emergency inverter loads and solar power production

If a household equipped with a solar-energy system and an emergency inverter were to experience a power outage, both the maximum load that could be connected as well as how much electricity the solar system can produce needs to be considered. Sweco has, therefore, analysed the maximum emergency inverter load, different appliance ratings and solar-power production in the nine countries included in the study.

Smaller loads can go a long way during a power outage

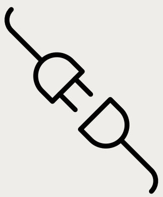
During a power outage, access to certain electrical appliances is more critical than access to others. With an emergency inverter and enough sunlight, a household with solar energy could thus use several different appliances, as long as the total capacity remained below 1.5–3 kW.

Emergency inverters can connect a load between 1.5–3 kW

When utilising an emergency inverter, the load capacity needs to be below the maximum load that can be managed by the inverter. Sweco has identified at least two emergency inverters on the market that allow for a maximum load capacity of 1.5–3 kW during a power outage, meaning that, if there is enough sunlight, a maximum 1.5–3 kW load can be connected to the inverter.

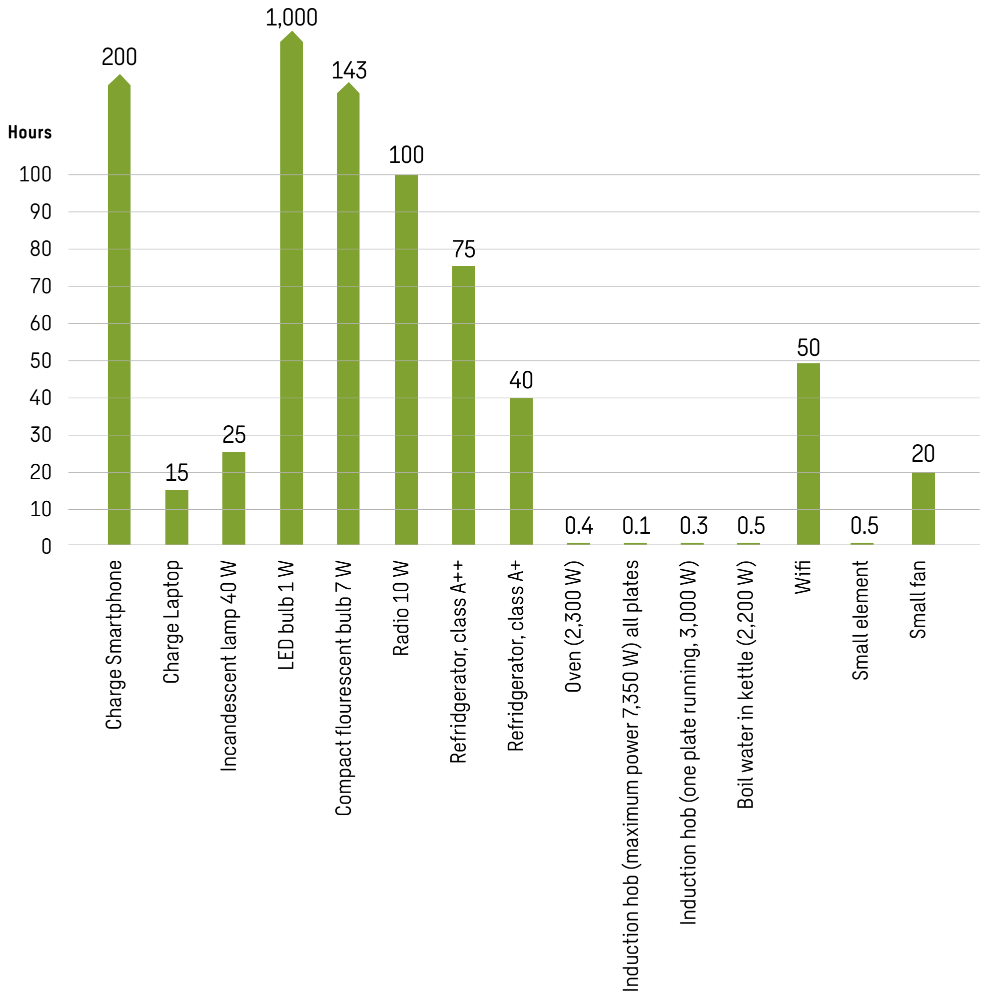
Max 3 kW

Appliance ratings vary significantly depending on the size and the type of appliance. Larger loads such as heating and cooling systems as well as cooking appliances, require far larger capacities than what an emergency inverter can manage. A visualisation of how long smaller appliances could run for on 1 kWh is presented in Figure 8. The graph provides a sense of how different large or small loads compare to inverter load capacity.



Charging your phone, having an LED light on, running a small fan or refrigerator is, therefore, well within reasonable loads for an emergency inverter. Further, the figure also shows significant differences between energy efficient appliances. Therefore, it can be of the outmost importance to consider changing to more energy efficient appliances to further protect oneself against power outages. Furthermore, it is important to mention that appliances will only have access to electricity when the sun is up and shining. Thus, appliances such as refrigerators could not have constant access to electricity with an emergency inverter.

Figure 8. Overview of how long different appliances can run on 1 kWh.[46]



Electricity production from solar energy

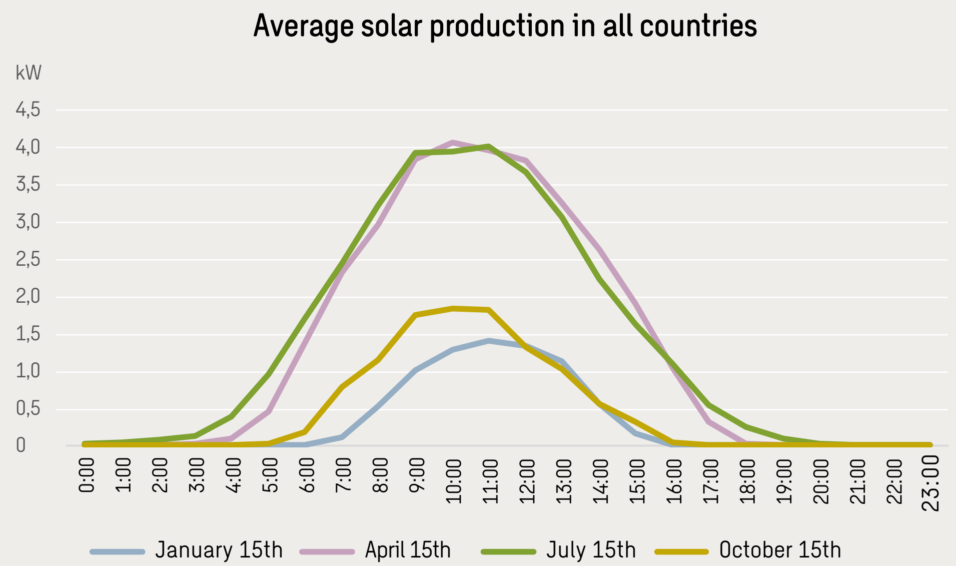
Solar-power production varies significantly between different countries, different locations in those countries, as well as during different seasons. Thus, the countries included in the study have different capabilities for producing enough solar power to supply the loads needed during a power outage.

Solar-power production differs depending on the season and on location

Regarding solar-power production, two different locations were selected in each country for this study, either north/south or inland/coast, which were then analysed four different times throughout the year. Large differences can be observed between different countries, different locations and in different seasons. In the northern parts of the Nordics, for instance, there is around 0 kW produced during the winter season. The opposite can be observed during summertime. For all countries, solar-power production reaches a maximum of 5 kW during the winter, while the output during summer is almost double that.

Figure 9 presents a simulation of the average daily solar-power production in each different country for 15 January, 15 April, 15 July and 15 October.

Figure 9. Average daily solar-power production in all countries compiled during four different days throughout the year and maximum emergency inverter load.[47]



Thus, the possibility of producing enough electricity to cover appliances during a power outage and thereby having access to electricity depends on where a plant is located and when the outage occurs. The inverter capacity of 1.5-3 kWh is, however, quite large compared to the identified critical appliances ratings, and most countries have enough sunlight during most periods of the year to produce enough electricity. However, it is important to mention that there is a small loss between produced electricity and electricity that can be used by the household. However, even if there is only a little sunlight during the day, this provides more resilience compared to not having access to electricity at all.

Batteries allow for greater self-sufficiency despite higher costs

A solar system with an emergency inverter can only produce electricity and supply loads when the sun is shining. Batteries can, however, be installed with a solar-energy system to achieve a higher degree of self-sufficiency during a power outage, as batteries are charged and store the surplus solar-energy electricity produced during peak hours. Batteries would thus enable electricity access during the hours after the sun has gone down.

Although higher self-efficiency can be achieved by using batteries, this comes with a significantly higher cost. The average cost for a full backup system for a single-family house ranges from EUR 3,000-15,000 for battery systems between 3-13 kWh[48]. The average battery size varies depending on the household and the size of the solar system installed, as well as on the desired functionality. Prices decrease with increased size of the battery.

Solar power resilience for critical infrastructure

There is technical potential to extend resilient solar-power solutions to critical infrastructure such as mobile communi-cations and water-management systems. There are, however, challenges to overcome.

Increasing resilience for critical infrastructure

Solar energy resilience potential for critical infrastructure

So-called critical infrastructure, e.g., water management, mobile communications, etc., have different requirements for reserve power, as larger shares of the population depend on them. According to, for instance, the PTS's (Post and Telestyrelsen in Sweden) regulations, assets that serve many users must have reserve power. In the event of a power outage, the requirement states that these critical assets must function for between a minimum of two and 24 hours.

In cities and communities, mobile radio stations are often located on the top of buildings. If these buildings also are equipped with solar-energy plants, it would be possible to use part of the solar production to supply power to mobile radio stations in the event of a power outage. Thus, the resilience (endurance) of the mobile radio station in question extends if a power outage occurs.

In some cases, mobile radio stations consist of separate installations next to a building. In such a case, it would be possible to feed the mobile radio station from a solar plant located on the top of a nearby building via a short electrical connection. This form of electricity supply should only be used when the regular electricity grid is interrupted. Similarly, the same scenario should be possible for, for instance, water pumping facilities if located near a building.

Building electricity resilience in this way for infrastructure is not something that is generally done today but could be technically possible. There are, however, some challenges related to, for instance, choosing functioning power electronics, as well as legislation, which can restrict the construction of parallel power grids. Although the challenges are numerous, if they were to be overcome, resilience in society would increase.

Advanced inverters can make it possible to transfer electricity to other areas

During warm weather periods with a lot of solar radiation and little electricity consumption, e.g., when a low proportion of electrically powered cooling machines are used, challenges with production congestion can occur in the grid.

In this situation, grid bottlenecks need to be overcome in order to transfer the electricity to other parts of the grid, where the electricity can be consumed. In order to avoid ending up in a situation with a risk of grid congestion, electricity-grid companies currently sometimes deny connection to solar plants. This is the case when the electricity grid hasn't been reinforced in order to cope with a higher production flow. If this situation occurs inverters are programmed to interrupt the delivery of electricity production to the grid.

With a more advanced inverter, however, it is possible for grid operators to limit the output to the grid during critical hours, instead of production being cut off completely. This is currently done in Germany. With a hybrid inverter along with a battery, it would also be possible to operate completely off-grid in situations where grid congestion occurs. In that case, it would, of course, not be possible to sell electricity back to grid; however, households could have access to the electricity.

If this technology is used, the end customer would be able to connect a solar plant to the electricity grid before it is reinforced and would simultaneously gain electricity resilience in the case of grid congestion. The technology exists; however, it is not commonly used. There are, however, aspects that need to be taken into consideration regarding the management of limiting output from homeowners' solar production. For instance, grid operators would need forecasts of load production, as well as surveillance systems and contracts.

Conclusions

Topic	Current and future solar energy	Potential resilience in 2028	Emergency inverter costs
Key findings	Solar power in the nine countries investigated currently varies significantly. In 2022, Germany had the highest installed capacity, while the Netherlands had the highest capacity per capita. Norway had the least installed capacity, far behind the top countries. Currently, various subsidies for solar installations are available in all countries; however, there are no requirements for emergency supply functionality. Looking forward, all countries expect the continued development of residential solar power, which cumulatively will increase by 40.4 GWp by 2028. The Netherlands, Belgium and Germany are expected to have the highest installed residential solar-power capacity per capita by 2028.	Sweco has reviewed the potential resilience that could be achieved through residential solar power and emergency inverters. If all those who installed residential solar energy between 2023-2028 would also install an emergency inverter, 8% of each country's population would have resilience during a power outage by 2028. If each household were able to provide electricity for three neighbouring households, 33% of a country's population would have resilience. The Netherlands have potential to cover almost 100% of the population. If all existing residential solar-energy systems, together with the estimated number expected to be installed between now and 2028, would include an emergency inverter, 17% of the population in all countries could achieve resilience. The Netherlands would again cover the largest share with 54% of the population.	An emergency inverter or hybrid inverter costs around 20-40% more than a normal inverter. Inverter prices have, however, decreased significantly in recent years; a study by NREL in 2021 shows a decrease of 55% between 2010-2020. Compared to a backup system with batteries, the average cost is between EUR 3,000-15,000 for battery sizes ranging between 3-13 kWh.
Key insights	Solar energy has clearly developed significantly in recent years in all countries and capacities are, though to different extents, expected to continue to increase in the future. The energy transition and decreasing solar prices and subsidies have been shown to be driving factors behind the development and might continue to be so going forward. The events of 2022 in Europe have led to increased interest in solar power, which can be seen by comparing the installed capacities in 2022 to 2021 in all countries. A shift towards increased energy independence is thus also expected to drive development further. Furthermore, increased regulations such as requirements for solar energy on new buildings, together with technological developments such as vehicle-to-grid charging and the integration of solar power into buildings/facades might also drive development forward.	Potential achieved resilience varies between countries, where some are likely to achieve higher degrees of coverage than others according to the estimated level of residential solar development. Although the study showed that the Netherlands have the highest potential for achieving resilience by 2028, all countries could boost resilience for an increased share of their populations in comparison to not having any at all. Countries with low solar-energy penetration today are in the position to be able to create greater electricity resilience in the upcoming years. However, as inverters need to be changed during the lifetime of a solar system, the study also shows that even higher shares of the population could achieve resilience if all current and future solar systems are installed with an emergency inverter.	According to the study, the benefit of having greater resilience in a power outage could be achieved for a 20-40% increase in costs, which comes to around EUR 350-650/inverter. As long as households receive subsidies for solar installations, it is, therefore reasonable for countries to require the installation of inverters to regulate emergency power in order to create more resilience in society. Furthermore, prices also have the potential to decrease with increased demand, as emergency inverters are currently not commonly found on the market and economy of scale could result in decreased prices. The additional cost of an emergency inverter is far smaller than a battery backup system; however, more resilience can be achieved with batteries.

Conclusions cont.

Topic	Load coverage	Critical infrastructure
Key findings	Emergency inverters found on the market can connect loads between 1.5–3 kW. Charging your phone, or having a light, radio, refrigerator or small fan on are within the reasonable loads for an emergency inverter; however, this does depend on available sunlight. Different countries do, however, have different capabilities to produce enough electricity to cover appliances during a power outage, as solar-electricity production varies significantly depending on location (north/south, inland/coast) and season. On average, European countries produce a maximum of approximately 1 kW (peak) in October and January and around 4 kW (peak) in July and April. Batteries can, however, be installed in order to achieve higher self-sufficiency during a power outage as surplus energy is stored. Thus, electricity would be accessible even when the sun has gone down.	There is theoretical potential for creating resilience for critical infrastructure, such as water management and mobile communications. If the critical infrastructure is either equipped with solar energy or located near a solar-power plant on a building, it would be possible to use part of that solar-power production to supply power to mobile radio stations in the event of a power outage.
Key insights	An emergency inverter cannot provide full back-up during a power outage for example it´s not enough for larger heating or cooling systems. However, the possibility for the average citizen to charge their phone or computer or for having light or occasionally a fridge on during a power outage can make life a little more comfortable. Batteries or other storage solutions can provide more resilience for a far higher investment cost. Subsidies for batteries are not available in all countries, which means that economic factors can prevent citizens from investing in systems that would provide greater resilience. Even with subsidies, the cost of batteries is higher than for an emergency inverter. Furthermore, the location and size of the PV system also sets boundaries on how much electricity can be produced and thereby consumed. The potential resilience, therefore, depends significantly on season and location.	Building electrical resilience for infrastructure in this way is not something that is generally done today but could be technically possible. There are, however, some challenges related to, for instance, choosing functioning power electronics as well as legislation, which can hinder the construction of parallel power grids. Although the challenges are numerous, if they were to be overcome, resilience in society would increase.

Outlook

Solar energy is clearly developing in Europe and will continue to play a role in the energy transition going forward. There are opportunities to simultaneously create resilience in society by integrating technical solutions such as emergency inverters for a small additional cost. The solutions available are currently quite immature and not widely spread on the market; however, there is potential to drive technological development with increased awareness and demand. Solar support schemes are found in all countries included in the study and, as long as funding is being provided by, for instance, governments, it would be reasonable to expect households to contribute and create greater resilience.

Although the technology for emergency inverters is currently most applicable to smaller loads and small-scale solar production, coverage for those who are unable to install solar energy in their homes, as well as resilience on a societal level, for instance, for critical infrastructure, should be considered and investigated further.

Emergency inverters do not provide full electrical backup; however, the potential for achieved resilience could facilitate everyday life compared to not having any electricity access at all. If more people choose to invest in resilient solar technology, we could create greater resilience in society as a whole.

Appendix

Appendix A: General assumptions per country

Country	**Definitions of small-scale PV**	**Other assumptions**
Sweden	0-20 kW	- Installed capacity in 2022 has been converted from MW to MWp by a DC/AC ratio of 0.9. - Average small-scale PV system size is based on installed small-scale capacity and number of small-scale facilities in 2022.
Belgium	0-10 kVA	- Data from the Flanders region have been used to calculate average residential solar-system size. - The number of facilities in all of Belgium in 2022 is estimated from numbers of facilities in the Flanders region and calculated average kWp per PV system. - The share of small-scale solar capacity in Brussels and Wallonia are assumed to be the same as for the Flanders region.
Germany	0–10 kW	- The number of small-scale facilities in 2022 is estimated based on the share of small-scale capacity and an assumption of average small-scale PV system size of 7 kWp. - Forecast is based on estimated total installed capacity by 2028. - The share of small-scale PV in the forecast is assumed to be the same as for 2022.
Norway	0–20 kW	- Installed capacity in 2022 has been converted from MW to MWp by a DC/AC ratio of 0.9. - Distribution of small-, medium- and large-scaled capacity based on values from 2021. - Forecast based on values of installed capacity for 2023, 2025 and 2030. The share of small-scale capacity in the forecast is assumed to be the same as for 2021. - Average small-scale PV system size based on installed small-scale capacity and number of small households in 2021.
Finland	0–10 kW	- Installed capacity in 2022 has been converted from MW to MWp by a DC/AC ratio of 0.9. - Average small-scale PV system size is assumed to be around 5 kWp. - The share of small-scale capacity in the forecast is assumed to have decreased from the current figure of 75% to 30% in 2030, as large-scale PV is expected to account for 50% in 2030. Further, a significant increase of medium-scaled PV is expected.
Denmark	0-10 kW	- Installed capacity in 2022 has been converted from MW to MWp by a DC/AC ratio of 0.9. - Share of small-scale capacity in the forecast is based on the current share and estimated decreased share of small-scale capacity to 1/3 of total installed capacity (assumed by 2026). - Average small-scale PV system size is based on installed small-scale capacity and number of small-scale facilities in 2022.
The Czech Republic	0–10 kW	- Average small-scale PV system size is based on installed small-scale capacity and number of small-scale facilities in 2022. - The share of small-scale solar energy in the forecast is assumed to be the same as for 2022.
The Netherlands	0–10 kW	- The forecast is based on Sweco's analysis of increased yearly capacity of 1,750 MWp/year to level out until 2025 and then drop below 1,500 MWp after 2025. - Average small-scale PV system size based on installed small-scale capacity and number of small-scale facilities in 2022.
The United Kingdom	0-10 kW	- Installed capacity in 2022 has been converted from MW to MWp by a DC/AC ratio of 0.9. - Forecast based on estimated total installed capacity in 2035. The share of small-scale solar energy in the forecast is assumed to be the same as for 2022. - Average small-scale PV system size is based on installed small-scale capacity and number of small-scale facilities in 2022.

Appendix B: Schemes for solar installations

Country	Type of support	Description	Outlook
Sweden	Tax deduction	20% tax reduction on grid-connected solar-energy installations and materials if performed by third party company. Increased from 15% to 20% 1 January 2023. Max EUR 5,000 per person, per year. Tax reduction is only provided for private individuals. Whether or not you can take part in the deduction depends on how much tax you have paid during the year and what other deductions you have made.	
Belgium	Premiums	The government of Belgium's Flanders region will halve the solar-energy premium for residential installations from 1 Jan 2023. The scheme was introduced in January 2021, after the region's net metering scheme ended, and it currently offers a premium of up to EUR 1,500. For solar panels commissioned in 2023, the premium will be reduced to a maximum of EUR 750. The contribution will be EUR 150/kWh for the first 4 kWp and EUR 75/kWh from 4 kWp to 6 kWp systems. In Brussels: Limited support as of 2023. One green certificate per 1.9 MWh (if installation < 5kWp) and per 1.8 MWh (if installation > 5KW but <= 39 KWp).	
Germany	Subsidies, loans, credits	Germany has an extensive support system in place for both solar installations and battery/storage solutions, which includes subsidies, credits and loans. Subsidy amounts are calculated via kWp/kWh mostly. Credit institutions are, for example, KfW, BAFA or regional institutions such as Nbank, Investitionsbank Sachsen-Anhalt or Investitionsbank Berlin. German schemes vary depending on federal state/region, as well as PV system size, as a distinction is made between small, medium-sized and large companies, private individuals and municipalities.	
Norway	Subsidies	There are grants available for private households that want to install solar power. The grants cover up to 35% of the documented total cost (including tax) up to NOK 7,500 for the production components and NOK 2,000 extra per kW up to 20 kW. This means that one can get up to NOK 47,500 for an installation with 20 kW. There are no grants available for businesses for the installation of solar power. The one exception is in Oslo municipality where a business can get up to 30% of the investment cost refunded.	
Finland	Tax credits, subsidies	Tax credits: Credits can be claimed for household renovation work, including solar installations. Credits can be claimed for 40% of the amount that will be paid to a company for their work. The maximum amount is EUR 2,250 per year, per person. Available for households and shareholders of a housing company, i.e., apartment owners. Housing companies can apply for energy aid granted by The Housing Finance and Development Centre of Finland. Energy Aid: A grant that can be used for solar-panel installations. Aid based on actual costs including work and equipment. The grant requires sufficient improvements to the energy efficiency of the residential building. The grant percentage for solar installation is 25% of the approved total costs. The maximum grant is EUR 4,000 or EUR 6,000 depending on the improvement on energy efficiency	
Denmark	Tax deduction	Since the early 2010's, the 'Nettoafregning' scheme has given private households an economic incentive to install solar-energy plants. This scheme has been modified several times and is currently not available for new installations. The scheme allowed private grid-connected installations to sell electricity at a fixed price and buy back at the market price. It is possible to apply for a minor tax deduction in relation to the installation of a small rooftop solar-energy plant. The tax deduction only relates to the expenses for installation work. The maximum reduction is 6,600 DKK.	
The Czech Republic	Subsidies	Call of the Ministry of Industry and Trade – RES: Designed for installations from 1 kWp to 1 MWp located on roofs and the cladding of business buildings including shelters. The rate of support is 35% for solar systems and 50% for battery storage outside the capital city and 45% in Prague. New Green for Savings: Ministry of Environment programme. Designed for family houses and apartment buildings connected to the distribution network. For family houses, the subsidy amount is CZK 40,000–200,000. For apartment buildings, the amount of the subsidy can reach up to CZK 500,000. Other available subsidies for companies and large-scale solar energy.	
The Netherlands	Subsidies, tax deductions	The main subsidy for the residential and small-business sector is called the 'salderingsregeling'. The subsidy allows for grid-connected households to deduct the energy yield from the usage of electricity on a year-by-year basis. Because of its success, there will be a change of regulation, probably from 2025 onwards. This will mean that the 'salderingsregeling' will be phased out, with an end date of 2031. Another support system is the possibility to deduct VAT from the purchase of solar-installation equipment. This results in a net benefit of 21%.	
The United Kingdom	Subsidies, VAT deductions	Subsidy: The Eco4 scheme in the UK is a government initiative that provides funding for low-income households to install energy-efficient measures in their homes, including solar panels. Eligible households can receive grants or loans to cover the cost of installing solar panels or other renewable energy systems. These grants or loans are funded by energy companies. Households must meet certain income and property criteria, and the specific eligibility requirements might vary depending on the local authority or energy supplier administering the scheme. Available until 2027. VAT: Homes will benefit from zero VAT on energy efficient measures for the next five years as the scheme is to start in April 2022 and will last until 2027. An average UK home can expect to pay between £5,000 to £15,000 for installing solar panels, dependent on the number of kWh's installed.	

Appendix C: Schemes for battery storage

Country	Type of support	Description	Outlook
Sweden	Tax deductions	Tax deductionsare given of 50 percent of the cost of labour and materials. Whether or not you can take part in the deduction scheme depends on how much tax you have paid during the year and what other deductions you have made.	
Belgium	-	The Flemish government offered financial incentives to homeowners investing in home battery storage systems. In 2023, the home battery premium was EUR 225 for batteries up to 4 kWh, EUR 187.5 for 4 kWh to 6 kWh, and EUR 150 for 6 kWh to 9 kWh. The Flemish Government has decided to accelerate the end of subsidies for the purchase or lease of a home battery. It was decided in principle that home batteries with an inspection certificate will no longer be entitled to the premium after 31 March 2023.	
Germany	Subsidies, loans, credits	Germany has an extensive support system in place for both solar installations and battery/storage solutions. However, schemes vary depending on the federal state, as well as PV system size. An example of storage schemes for owners of one- and two-family houses in Berlin includes 300 euros per kilowatt hour of usable storage capacity.	
Norway	-	There have been discussions about establishing a nationwide funding scheme for batteries, but this is not the case yet.	
Finland	Tax credits, energy aid	Available for household repairs and improvements. Credit can be claimed for 40% of the amount that will be paid to a company for their work. The maximum amount is EUR 2,250 per year, per person. Aid can be granted for measures that include "innovative solutions that have an impact on energy efficiency or have significance in terms of demand response or are otherwise beneficial for the residential property owner in terms of energy".	
Denmark	-	There are currently no existing grants or support schemes for installing or storing electricity in private battery electricity-storage systems.	
The Czech Republic	Subsidy	Call of the Ministry of Industry and Trade – RES: Designed for installations from 1 kWp to 1 MWp located on roofs and the cladding of business buildings including shelters. The rate of support is 35% for solar systems and 50% for battery storage outside the capital city and 45% in Prague	
The Netherlands	-	There are no grants for small-scale batteries in the Netherlands. Also, the 'salderingsregeling' makes the installation of batteries in households financially unattractive. The expectation is that with the phasing out of the 'salderingsregeling', the market for small-scale batteries will grow. There are arguments in the Netherlands for supporting battery storage. Grid congestion due to intermittent power generators (wind and solar) has become a serious problem. As a result, the market for large-scale battery energy-storage systems has already exploded.	
The United Kingdom	-	There are currently no grants or support available for batteries for domestic solar systems.	

Appendix D – Data used in cases one, two and three.

Country	Installed capacity 2023 (MWp)[49]	Installed capacity 2028 (MWp)[50]	Population 2023 (millions)[51]	Population 2028 (millions)[52]	Average solar-system size (kWp)[53]	Average household size[54]
Belgium	5,778	8,222	11.7	11.9	4.4	2.6
The Czech Republic	540	996	11.0	10.9	8.6	2.5
Denmark	685	975	5.9	6.0	5.3	2.1
Finland	581	1,856	5.6	5.6	5	2.7
Germany	16,450	37,333	84.6	85.3	7	2.1
The Netherlands	9,267	16,000	17.8	18.2	3.8	2.3
Norway	155	597	5.5	5.6	8.8	2.1
Sweden	1,782	3,222	10.6	10.9	11.4	2.7
The UK	5,734	12,187	67.7	68.8	3.6	2.4
Total	**40,972**	**81,389**	**220.4**	**223.3**	**6.4**	**2.4**

Appendix E – List of acronyms and abbreviations

Acronyms and abbreviations	
AC	Alternating current
CAGR	Compound annual growth rate
DC	Direct current
PV	Photovoltaics (solar power)
kWp	Kilowatt-hour peak
MWp	Megawatt-hour peak
GWp	Gigawatt-hour peak

Glossory list	
kW/MW/GW vs kWp/MWp/GWp	KW/MW/GW measures the output power from solar energy after it has been converted from DC to AC power. kWp/MWp/GWp are the output from the solar-power plant in DC and thereby peak power.
Inverter	System component that converts DC produced power from solar-energy panels to AC power fed to the grid or household.
Hybrid inverter	Inverter used for solar-energy systems connected to the grid and with battery storage. Functions during a power outage if batteries are connected to the system.
Emergency inverter	Inverter used for solar-energy systems connected to the grid. Functions during a power outage with or without batteries.
Small-scale	Residential solar energy installed on household rooftops. Usual capacities below 10 kWp.
Medium-scale	Commercial and industrial solar energy installed on rooftops. Usual capacities between 10–1000 kW.
Large-scale	Utility scale, usually includes solar parks and ground -mounted solar energy with capacities above 1000 kW.
Tilt	A solar power plants' tilt is the slope by which it is angled from the plane.
Azimuth	A solar-power plants' azimuth is the orientation by which the plant is directed.

About the Authors

Feel free to contact us with your questions and thoughts. E-mail: urbaninsight@swecogroup.com

Magnus Lindén is part of the energy markets team in Stockholm, Sweden. Magnus has worked with energy systems since the late 1990s. Today, Magnus mainly works on the energy transition, efficient electricity grid utilisation and multidisciplinary urban planning.

Bezawit Tsegai is part of the advisory services team in Stockholm, Sweden. She works with strategic topics within the energy sector such as due diligence and market studies in the Nordics, Baltics and northern Europe. Her Master thesis examined solar energy resilience in Addis Ababa, Ethiopia.

Alexandra Lybaert — Program Manager for Energy Transition, Belgium
Marc van Leeuwen — Consultant, Sustainable Energy, the Netherlands
Bert van Renselaar — Business Director, Energy Transition, the Netherlands
Gary Marshall — Buildings Services Director (Research and Lead Author), the United Kingdom
Merve Tarakci — Senior Electrical Engineer (Research and Co-Author), the United Kingdom
Håkon Blågestad — Project Engineer, Norway
Eirik Hordnes — Energy Technology and Electrification Expert, Norway
Franca Dömer — Project Manager, Germany
Pia Fürbach — Project Manager, Germany
Matthias Lohoff — Project Manager, Germany
Maximilian Much — Student Support, Germany
Markus Harju — Energy Consultant, Finland
Mikkel Kamari-Kany — Energy Consultant, Denmark
Pavel Frelich — Director of the International Business Department, the Czech Republic
David Műller — Senior Electrical Project Designer, the Czech Republic
Hugo Jennehov — Energy Advisory Specialist, Sweden
Madeleine Johansson — Power Systems Analyst, Sweden

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2) Sweco analysis
3) Bundesnetzagentur (The Federal Network Agency) (2023)
4) Norwegian Water Resources and Energy Directorate (NVE) (2023)
5) StatLine (CBS) (2023) and Sweco analysis
6) Yle (2023) and Fingrid
7) Energie Commune (2022)
8) Energimyndigheten (The Swedish Energy Agency) (2022) and Sweco analysis
9) *Norway, Denmark and Finland have reported data for installed solar-energy capacity from the beginning of 2023. Sweden, Norway, Denmark, Finland and the UK reported installed capacity in MW, which has been converted to MWp with an DC/AC ratio of 0.9.
10) Eurostat (2022) and United Nations (n.d)
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12) Rijksoverheid (n.d), The Eco Scheme (n.d)
13) Colours represent Swecos analysis of the risks related to availability or changes in the future. Green = low risk, yellow = medium risk.
14) Source for regional spread: Energie Commune (2023), Energimyndigheten (2022), UK Government (2023), Bundesnetzagentur (The Federal Network Agency Germany) (2023)
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28) UK Government (2023)
29) MCS Service Company Ltd (n.d)
30) Sweco analysis, assumptions presented in Appendix A. For all countries, except the Netherlands and the Czech Republic, capacity has been converted from MW to MWp with an DC/AC ratio of 0.9.
31) Eurostat (2022), United Nations (n.d) and Sweco analysis.
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38) International Energy Agency (IEA) (2022)
39) HM Government (2023)
40) MCS Service Company Ltd. (n.d)
41) *Household growth corresponds to the additional number of households with solar energy between 2023-2028
42) *Households 2022 corresponds to the number of households in 2022 that would need to change inverter
43) National Renewable Energy Laboratory (NREL) (2021)
44) Sweco analysis
45) National Renewable Energy Laboratory (NREL) (2021)
46) Mälarenergi Sverige (n.d), Eksjö energi (2022), and Sweco analysis
47) The solar tilt was set to 30° and the azimuth to 0° in all countries, which might result in less optimal readings for some locations.
48) Sweco analysis
49) International Energy Agency (2022), Plan- og Landdistriktsstyrelsen (2023), Yle and Fingrid (2023), Norwegian Water Resources and Energy Directorate (NVE) (2023), HM Government (2023). For all countries except the Netherlands and the Czech Republic, capacities have been converted from MW to MWp by a DC/AC ratio of 0.9.
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51) Eurostat (2022), United Nations (n.d) and Sweco analysis.
52) Eurostat (2022), United Nations (n.d) and Sweco analysis.
53) The average solar panel size has been calculated by the number of solar-panel installations and installed capacity (small-scale)
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