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Barriers and potential solutions to the diffusion of solar photovoltaics from the public-private-people partnership perspective – Case study of Norway

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ABSTRACT

Norway is a major renewable energy developer in Europe, mainly through its development of hydropower. Research has shown that solar energy also has potential in Norway, however, the cumulative installed photovoltaic capacity was only 120 MW at the end of 2019, representing 4.1% of the total electricity generation. Hence, this paper aims to investigate the main barriers to diffusing photovoltaics for residential buildings from the public sector, private sector, and the people's perspectives in Norway. Furthermore, it analyzes solar development, policies, and models in different countries, and proposes a potential model and solutions to overcome barriers. The results show that the high initial costs of photovoltaics and limited information and awareness of the possible benefits are the main barriers for the people. For the private sector, limited funding and few pilot projects to learn from, as well as risk uncertainty are the main barriers. The main concern in the public sector is the low application of existing incentives. Public-private-people partnerships (PPPP) have a big potential to overcome these barriers by dividing the high initial costs into more affordable sums, facilitating the information flow among different sectors, and involving all three sectors to create new incentives. In addition, Norway is well-suited for PPPP, as the citizens pay much attention to sustainable development, and there is already a close collaboration between the public and private sectors in the energy sector. Finally, three concrete solutions using PPPP are proposed: design a co-investment solution, provide information sharing platforms, and create new incentives.

1. Introduction

The diffusion of solar photovoltaics (PV) is considered a potential method for achieving energy efficiency, environmental sustainability, and socio-economic development [1]. According to the PV annual report conducted by the International Energy Agency (IEA) [2], the yearly installed PV capacity has increased significantly in recent years. The global annual PV capacity installed in 2019 was at least 114.9 GW, which led to the cumulative installed PV capacity increasing to 627 GW [3].

Countries such as Brazil, Canada, and Sweden, have a strong dependence on hydropower, accounting for 70%, 62%, and 42% of their total energy production, respectively, while having a mixed energy production [4–6]. Norway has a strong hydropower industry, with a higher dependence than other countries, that produces energy equal to 93% of the country's energy generation in the form of low-cost and clean electricity. Still, there are many advantages to developing solar energy. The first reason for developing solar is seasonal variations in demand. During the winter, when demand is high, electricity from hydropower alone is not enough to cover the whole domestic consumption in Norway, and importing energy becomes necessary [7]. In 2018, Norway imported 8 340 GWh of electricity [7], generated mainly from oil, gas, and coal [8]. By investing in PV, this can be replaced with clean renewable energy, reducing CO2 emissions globally. At the same time, Norwegian citizens need to pay a higher electricity price in dry seasons when generated hydroelectric energy is low [9,10]. Data shows that the cost of electricity from solar PV is lower than buying electricity from the grid. Assuming a lifespan for PV panels of 30 years, the average cost of the generated electricity in southern Norway is 0.69 NOK/kWh [11]. Although hydropower by itself is considerably cheaper (0.48 NOK/kWh

Abbreviations: PV, photovoltaics; BIPV, building-integrated photovoltaics; PPP, public-private partnership; PPPP, public-private-people partnerships; TPO, third-party ownership; CS, community shared; IEA, International Energy Agency; GW, gigawatts (10^9 W); MW, megawatts (10^6 W).

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in 2018), buying electricity from the grid cost on average 1.15 NOK/kWh in 2018, due to grid fees and governmental taxes [12]. The second reason is to secure a more stable energy production by becoming less dependent on a single source of energy. In fact, the past two years have seen a decline in the output from hydropower, due to the lower rainfall and colder winters, which limit the energy supplies [9]. Uncertainty around hydropower output has been addressed in Brazil, for example, by developing multiple kinds of non-hydroelectric energy including solar energy [4]. Third, due to environmental and aesthetic concerns, many Norwegians are against installing new hydropower stations [13]. Canada has started to develop other nonhydroelectric energy after realizing the environmental and social issues caused by hydropower projects, such as disruption of fish migration and habitat loss for several species [14].

In addition, research has shown that solar energy also has great potential in Norway. Specifically, a recent report found the energy output per square meter of solar in the South of Norway to be comparable to that of Germany [15]. Furthermore, the cold climate is beneficial for solar energy production, as it prevents PV panels from overheating [16]. Finally, Norway has a strong silicon industry, which is the main component in PV panels [17]. There has been a recent increase in installed PV capacity with these advantages, however, the cumulative installed solar photovoltaic capacity was 120 MW at the end of 2019, representing only 4.1% of the total electricity generation in Norway [18]. Hence, exploring the barriers to diffuse solar PV in Norway is valuable.

The adoption of solar PV is influenced by different stakeholders and their cooperation. In the solar PV market, the main stakeholders are energy-related government departments, financing institutions, solar PV suppliers, consulting companies, skilled workers, and end-consumers [19]. These can be classified into three sectors: public (institution), private (commerce), and people (residents) [20]. The public sector refers to policy-making departments and related institutions supported by the municipalities or the government [21]. The private sector refers to private companies involved in solar projects, such as financing institutions, management companies, supplier companies, and consulting companies [22]. The people refer to end-consumers [22]. Fig. 1 shows the public sector, private sector, and people visually.

The different sectors have different concerns about the impact of solar PV on the society, economy, and environment. The public sector mainly focuses on the achievement of energy goals, the efficiency of PV incentives, and social acceptance for PV [23], while the private sector tends to focus on the profits, payback time, and risks [24]. The people mainly focus on the loan amount, payback time, as well as financial and environmental benefits [25]. Therefore, the barriers for diffusing solar in Norway will be explored from the perspective of the people, public, and private sectors.

In addition, using a suitable form of partnership is a potential method to overcome the barriers for diffusing solar PV [26]. Specifically, partnerships between different sectors can utilize various sectors' resources [27]. Furthermore, they facilitate the information flow among different sectors, which results in new co-production of PV knowledge and forms shared value [28]. Finally, it can increase opportunities for PV projects, as it allows partners to share the high costs, making them more affordable and reducing individual risk [29].

Partnerships have been applied to promote solar PV in several countries successfully. Specifically, China employs public-private partnerships in the form of the government providing financial support to large private organizations, which greatly promotes the PV market [30]. USA does this through the third-party ownership (TPO) model [31], while Spain has seen an increase in solar PV installation through community partnerships, particularly crowdfunding and community solar models [32]. In the following, detailed information about the partnerships and models in different countries will be introduced and analyzed, and a potential model for Norway will be proposed.

Therefore, this paper aims to: analyze the solar PV development, policies and models in different countries; explore the main barriers for the diffusion of solar photovoltaics in the people, private, and public sectors in Norway; analyze and discuss a potential model in Norway compared with the existing models, such as host-owned, third-party, and community shared models; describe the potential solutions to the identified barriers according to the Norwegian context.

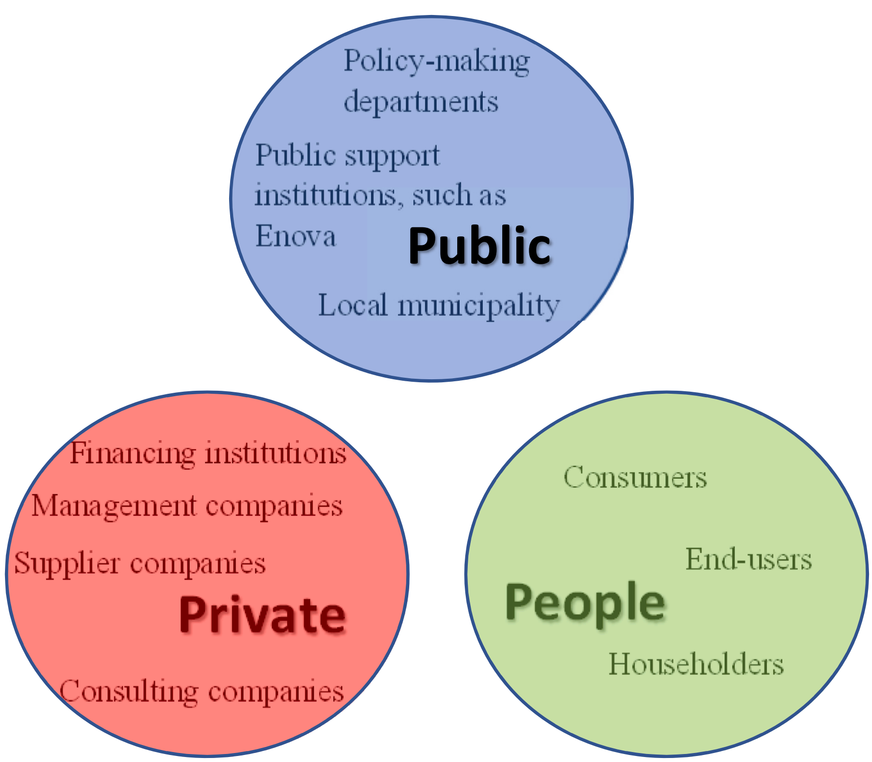

Fig. 1. Public sector, private sector, and people in the context of solar PV.

2. Background

2.1. Global trends of solar PV

The data in this paragraph concerning the global solar PV development are mainly from the Snapshot of Global PV Markets 2020 report [3]. According to the report, 114.9 GW of solar PV was installed globally in 2019, which led to a total cumulative installed capacity for PV of 627 GW. China remained the leader with 30.1 GW installed in 2019, followed by the European Union installing close to 16 GW. The largest contributors among them are Spain (4.4 GW) and Germany (3.9 GW). The US installed 13.3 GW, followed by India with 9.9 GW and Japan with 7 GW [3]. The annual installed capacity in Norway was 51 MW in 2019 [33], compared to other Nordic countries, for example, 287 MW in Sweden [34]. Installations of solar PV in Norway are comparatively low on a global and Scandinavian scale for Solar PV.

2.2. Policies and models in PV leading countries

Before analyzing the policies and models for developing solar PV in different countries, the general economic policies and models for diffusion solar PV will be introduced. The policies mainly include feed-in tariff (FIT), feed-in premium (above market price), green certificates, income tax credits, tax exemptions, self-consumption, collective self-consumption and virtual net metering, and building-integrated photovoltaics (BIPV) incentives [32,35,36]. The main models can be classified into three main patterns based on the ownership aspect for solar PV, namely, host-owned model, TPO model, and community shared (CS) model [37]. The host-owned model is the most widely used pattern, where the owner of the building invests in, owns, and uses the generated electricity from the PV panel with support from government incentives [37]. The TPO model is a type of private-people partnership, in which a third party (generally a private investment company or a private bank) invests in and owns the PV products, and the citizens pay a renting fee in return for electricity [31]. The CS model is a form of community partnership, which allows large groups of citizens to invest in solar PV as a community. The investors do not have to be building owners, but will have access to the generated energy as long as they invest in the project [38]. There are two main types of CS models: crowdfunding and community solar. Crowdfunding is a type of financing model where a large number of people invest and get financial benefits from an organization [39]. Community Solar is a model for indirectly purchasing energy by leasing or buying PV arrays in a solar plant, which allows multiple participants to directly get energy from the output from solar PV [38].

To learn from the PV leading countries, China, USA, Spain, and Sweden were chosen for deep analysis. This not only because they have higher installation capacity, but also because they can represent different social situations. Different measures should be applied according to their contextual background. An analysis has been made on solar PV related policies, financial models, driving sectors, and partnerships from the PV annual report in China [40], USA [35], Spain [32], and Sweden [36] (see Table 1).

The policies for promoting solar PV in China include feed-in tariffs (FIT) and BIPV incentives [40]. The main driving sector in China is the public sector, which promotes the solar market through FIT policies and organize large national projects through public-private partnership (PPP) [40]. There is no main financial model according to the 2019 annual PV report, but the host-owned, TPO, and CS model exits to some extent [41].

In USA, there are a diverse mix of policies, including feed-in tariffs, feed-in premium, capital subsidies, green certificates, income tax credits, self-consumption, collective self-consumption, and virtual net-metering [35]. The driving sectors are both the public and private sectors [42]. The incentives from the public sector, such as capital subsidies, feed-in tariffs, and green certificates have developed well since they were established [35]. Another main driver in USA is the private sector, which pushed the development of TPO and greatly promotes PV market development [42]. Therefore, the main partnership in USA is the people-private partnership. The people are also starting to play an important role in promoting the solar PV market through the CS model [35].

Spain had the largest annual solar PV installation in the EU in 2019. Their policies mainly aim to promote self-consumption, including the right to sell surplus electricity for at least market value, and no charges for self-consumed energy for installations producing less than 30 kW. In addition, TPO of the PV facilities and collective self-consumption and virtual net-metering are allowed, and there are BIPV incentives and tax exemptions [32]. The main driving sectors are the public and people in the form of tendering auctions and a positive attitude towards self-consumption from the citizens [18]. This is because of the relatively low price on PV components and high solar irradiation, resulting in self-generated electricity being cheaper than standard electricity from

Table 1
Policies, models, driving sectors, and partnerships for developing solar PV in China, USA, Spain, and Sweden.

Country	Main policies	Main financial models	Main driving sector (s)	Main partnership	References
China	Feed-in tariffs BIPV incentives	There is no main financial model according to the annual PV report in China, but the host-owned, third-party, and community shared model exist to some extent	Public	Public-private partnership	[40]
USA	Feed-in tariffs Feed-in premium Capital subsidies Green certificates Income tax credits Self-consumption Collective self-consumption and virtual net- metering	Third-Party Ownership Leasing Community solar Crowdfunding	Private; Public	People-private partnership	[35]
Spain	Self-consumption Collective self-consumption and virtual net-metering BIPV incentives Tax Exemption	Third-party ownership Crowdfunding Community solar	Public; People	Community partnership	[32]
Sweden	Feed-in premium Capital subsidies Green certificates Income tax credits Self-consumption Collective self-consumption and virtual net-metering	Third-party ownership Renting Leasing Crowdfunding Community solar	Public; People	People-private partnership; Community partnership	[36]

the grid [18]. Citizens can also achieve self-consumption with different models, such as TPO, crowdfunding, and community solar [32]. Community partnership is the main partnership form for solar PV in Spain.

Among the Nordic countries, Sweden, installed the most solar PV in 2019 (287 MW), which is more than five times Norway's capacity [34]. The main driving sector is the public sector, which provides incentives in the form of feed-in premiums, capital subsidies, green certificates, income tax credits, allow for self-consumption and collective self-consumption [36]. In addition to the public sector, the people in Sweden have a good acceptance of solar PV. In an annual survey, 81% of respondents wanted more investments in PV in Sweden [18]. Due to the positive attitude and existing policies, a wide range of financial models exists, such as host-owned model, TPO, crowdfunding, and community solar. The main partnerships in Sweden include private-people partnerships and community partnerships.

2.3. The Norwegian context

Norway is a major renewable energy developer in Europe. Renewable energy sources include hydro, wind, and solar power. In 2019, hydropower generated 135 TWh electricity, representing 93.4% of the Norwegian electricity production, while wind power and solar power only represented 2.5% and 4.1%, respectively [43].

Although there is no clear goal to diffuse PV in Norway [44], the annual installed capacity of solar PV has increased every year from 2012 to 2019 (see Fig. 2). Continued decline in prices of PV components and rising prices on hydropower due to lower rainfall, as well as more attention to solar energy led to an increase in 2018–2019 [45]. However, the total installed capacity was still only 120 MW in 2019.

Policies and business models played a significant role in PV leading countries, however, they have been less successful in Norway. Specifically, in China, the total annual installed capacity increased by 306% in 2013 and increased by 200% in 2014 compared to the previous year, due to a series of efficient incentives, such as direct financial subsidies, explicit monetary rewards, and feed-in tariffs [46,47]. In the US, the installed capacity increased from 753 MWp in 2008–51,738 MWp in 2017 gradually through various kinds of incentives, such as feed-in tariffs, capital subsidies, green certificates, income tax credits, as well as the different kinds of business models, such as TPO, community solar, and crowdfunding [35]. In Spain, the increase in installed capacity was quite big in 2019 due to the tender auctions approved in 2017 for accomplishing the de-carbonization compromises with the European Union [18]. Sweden installed the most solar PV among the Nordic countries in 2019 (287 MW) using policies and different kinds of financial models, such as TPO, renting, leasing, crowdfunding, and community solar [34]. In Norway, the existing financial incentives, such as feed-in tariff and capital subsidies have been around for about 10 years, however, there has not been any significant increase before 2015 (see Fig. 2). And the financial model TPO has hardly applied. There has been a rapid growth in solar deployment recently, mainly due to the decreasing costs of PV components and the higher electricity price of hydropower [48]. This means that in addition to the policies, providing new suitable models to promote the market like the leading countries are needed to overcome the existing barriers.

There are two main contextual factors that hinder the diffusion of solar energy in Norway, which are different from other countries. The first is the abundance of hydropower, which has a lower levelized cost of energy (LCOE) than solar in Norway. The data in the remainder of this paragraph is from the Renewable Power Generation Costs in 2019 report conducted by IRENA [49]. Between 2010 and 2019, the global LCOE of solar PV fell by 82% to USD 0.068/kWh in 2019, mainly thanks to the 90% decline in the prices of PV panels and supporting systems. However, the LCOE of solar PV is still higher than hydropower, whose LCOE increased from USD 0.037/kWh in 2010 to USD 0.047/kWh in 2019. Another available resource in Norway is wind power, and over the past ten years, the cost of onshore wind power has decreased by 40% to USD 0.053/kWh, which is lower than for solar PV.

The second obstacle is the high latitude and relatively low solar intensity. This leads to less motivation for citizens to invest in solar energy, limited pilot PV projects in the private sector, and controversy in the public sector over whether to focus on hydropower or to develop solar. The average daily solar irradiation in Norway is 2.46 kWh/m^2 [50], compared to 3.2 kWh/m^2 in Germany [51]. It is only 0.1 to 0.35 kWh/m^2 during winter months, however, during summer it is between 4.0 and 5.5 kWh/m^2 [50]. The average daily solar irradiation map of Norway for January and July is show in Fig. 3 [50]. In some southern parts of the country, the solar irradiation can reach more than 5.5 kWh/m^2 during the summer, which makes it not only possible but also

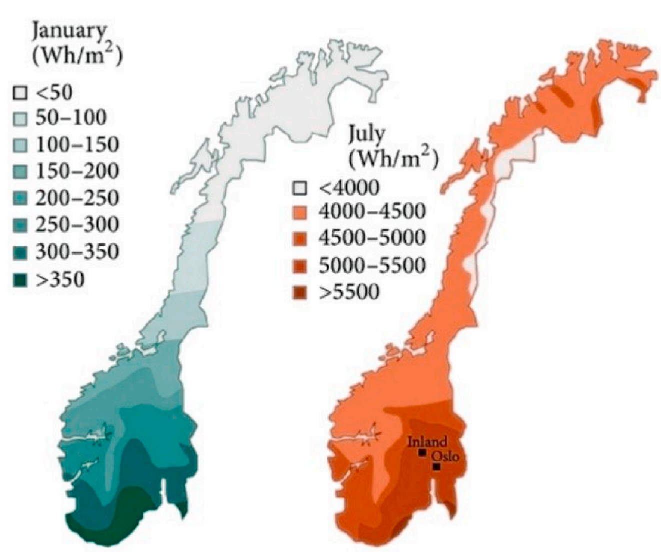

Fig. 2. Yearly installed capacity from 2012 to 2019 for solar PV in Norway. (Source: IEA PV annual report for Norway)

Fig. 3. Average daily solar irradiation map of Norway in January and July [50].

profitable to develop solar energy [50]. Fig. 4 shows the location of the ten PV plants in Norway with the highest installed capacity in 2017 [52]. As can be seen in Fig. 4, the plants are all located in areas with relatively high solar irradiation. According to an experiment conducted by Midtgard [53], an area of 50 × 50 km^2 in southern Norway covered with solar PV could match the current energy production from hydropower, which is at 120 TWh. The experiment also shows that the average monthly energy yield in the four seasons is 7.6 kWh/m^2, 13.1 kWh/m^2, 10.6 kWh/m^2, and 3.5 kWh/m^2 respectively for a multi-crystalline silicon PV model.

Several attempts from different sectors have been made to encourage the development of solar PV. The main driving sector in Norway is the public with policies to promote solar PV, including electricity certificates, capital subsidies, and self-consumption. The public sector issues electricity certificates to stimulate electricity generation from renewable energy sources [44]. However, it is not suitable for small scale projects and residential areas, due to high registration fees. For the residential area, the public agency Enova SF subsidizes up to 35% of the installation costs for grid-connected residential PV systems at a rate of 10,000 NOK (1 NOK = 0.11 USD) per installation and 1250 NOK per installed kWp up to 15 kWp [44]. Enova is a government-owned institution in Norway, whose role is to explore new sources of clean energy to ensure a more secure energy supply, reduce greenhouse gas emissions, and develop new materials and technologies [54]. Every year, Enova invests more than 2 billion NOK in solutions for sustainable development in Norway [55]. Furthermore, self-consumption and the possibility of selling generated surplus electricity back to the grid are other types of incentives provided by the public sector [56]. In addition, the Research Council of Norway funded about 83 million NOK (~9.1 million USD) in solar-related R&D projects in 2018, mostly in PV [56].

In the private sector, the silicon industry receives much attention [57]. The abundance of raw materials and cheap electricity from hydropower are the basic advantages to develop the silicon industry in Norway [58]. From the investment aspect, some private financial institutions provide support mainly through the TPO to promote the diffusion of the PV system. However, few financial institutions are currently willing to invest [59].

At the same time, some citizens are willing to invest in solar PV. According to an interview conducted by Winther, Westskog, and Sæle [60], these citizens include people who are interested in being both an investor and consumer for solar PV, have a desire to live in houses with modern technologies and functional automation, and wish to be environmentally friendly.

3. Method

First, a scoping review was conducted to explore the main barriers to the diffusion of solar photovoltaics in Norway. The relevant findings were identified through a three-step process: (1) structured search, (2) snowball-technique search, and (3) narrowing and summarization of the research. Keywords "barriers", "obstacles", "encumbrance" AND "photovoltaics", "solar energy", in Norway were used in the search. The initial search returned little information about the barriers to photovoltaics in Norway. The scope of the keywords was therefore extended to "PV", "photovoltaics panel", and "renewable energy", "solar energy" AND "Norway". The titles and abstracts of these papers were checked for a discussion about barriers. At the same time, a snowballing search (checking backward and forward citation tracking of identified articles [61]) was conducted for each identified paper. The source data were mainly from Science Direct, Web of Science, Google Scholar, Scopus, ACM Digital Library, and IEEE Xplore. Information collected included the title, authors, keywords, aim, methodology, results, and recommendations for further study.

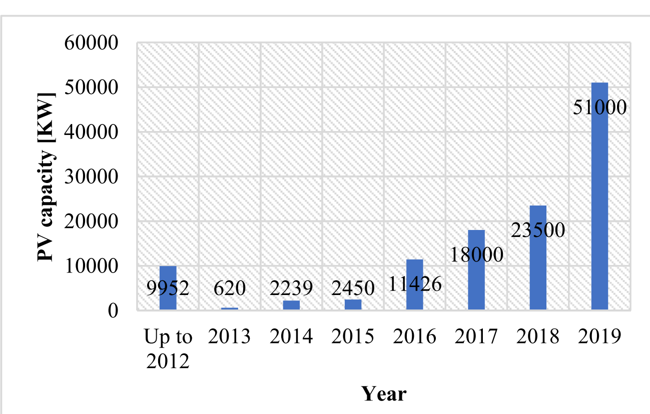

Fig. 4. Locations of ten largest solar PV plants in Norway.

Second, data analysis. The adoption of solar PV is influenced by different sectors and their cooperation. The different sectors have different concerns about the impact of solar PV on the society, economy, and environment. Therefore, the barriers for diffusing solar in Norway were classified from the people, public, and private perspectives. At the same time, the barriers that were found could be classified into three groups: (1) financial problems; (2) information sharing problems; (3) risk and uncertainty problems. This was used for the following analysis of the potential model.

Third, the IEA's annual reports on PV development were studied to determine the leading countries in terms of PV installation. In order to understand how they had promoted the development of solar PV, information about their strategies, such as policies, financial models, driving sector(s), as well as partnership forms, were studied. Here, China, USA, Spain, and Sweden were chosen for deep analysis, not only because of their high installation capacity, but also because they can represent different social situations. The analysis, combined with knowledge about the Norwegian context, were then used to propose a potential model for Norway.

The ability of public-private-people partnerships (PPPP) to overcome the identified barriers was then compared to that of existing business models, such as the host-owned model, third party ownership model, and community shared model. The feasibility of applying the PPPP model in Norway was also analyzed. Finally, three concrete solutions to the identified barriers were proposed based on the PPPP model.

4. Results

There are many types of barriers before, during, and after the process for installing PV panels. This paper focuses on the main non-technical barriers, which receive much attention from the majority of research on the diffusion of solar PV in residential areas in Norway. Table 2 shows an overview of the barriers, categorized according to sectors.

Table 2
Main barriers for people, private, and public sectors.

Sector	Main barriers	Reference
People	High initial cost, as well as limited financial support	[15,17,62–65]
	Satisfaction with the current electricity system	[62,63,66]
	Limited information and awareness of the possible benefits	[15,17,62,63,65,66]
	Uncertainty	[15,62,63,65]
Private	Limited access to capital	[15,17,65,67]
	Limited PV project examples	[67,68]
	Uncertainty surrounding risks	[15,17,65,67,68]
	Lack of communication among different stakeholders	[15,17,67,68]
Public	Lack of efficient incentives	[17,65]

4.1. Barriers from the people's perspective

From the people's perspective, the barriers mainly come from four aspects, namely high initial cost, satisfaction with the current electricity system, limited information surrounding the possible benefits, and uncertainty.

(1) High initial cost, as well as limited financial support

In a survey on solar PV answered by 803 residents in Norway, 34.6% stated the high cost as the main barrier for diffusing solar PV [62]. In Norway, the PV panel covered rooftop of a typical residential house can produce between 5 and 10 kW, while the current prices are about 15 NOK (1 NOK = 0.11 USD) per W for grid-connected PV panels [56]. This means that the typical investment for one house is about 75,000–150,000 NOK. The public support institution Enova covers 10–30% of the cost for citizens, however, they will still need to pay approximately 50,000–105,000 NOK for installing PVs on one house [44]. Furthermore, since residents often already have a home mortgage [56], it is difficult for them to increase their loan amount according to their payback ability.

(2) Satisfaction with the current electricity system

Many residents in Norway are satisfied with the current price of electricity bills due to hydropower [69,70]. In addition, hydropower is renewable and produces enough energy for the gross domestic electricity consumption [44], and some citizens believe that there is no need to invest in other types of energy [66]. A study shows that 60% of the citizens have a very positive attitude towards hydropower while 35% have a somewhat positive attitude [71]. However, the main attitude towards solar PV is lack of interest, and 73% of the citizens would not consider installing PV panels [62]. As more wind power plants have been installed in recent years, the attitude towards wind power in Norway has gradually worsened. According to a recent survey, 15% were somewhat negative towards wind power, and 28% were very negative [72]. This is because citizens think the windmills ruin the natural scenery and interferes with local wildlife [72].

(3) Limited information and awareness

Many residents know little about the possible benefits of installing PV panels due to the limited number of PV projects and information sharing in Norway [15]. Reliable information about financial costs and benefits, electricity output, related incentives, and potential benefits to the environment is not easy to find from Norwegian projects [17,62,63,65,66]. Furthermore, citizens lack information about the installation process, such as the suitability of the house and the length of time for the installation [66].

(4) Uncertainty

There are different types of uncertainty in the process of installing PV panels, which hinder the citizens' willingness to invest. First, residents are not sure about the energy output of PV in Norway, because the duration of sunshine is very short in the winter [63]. Second, the development of PV panels is still in its early stages in Norway, which leads to uncertainty around the future policies and regulations on PV panels, as well as its long term benefits [65]. Third, citizens worry about uncertainty and potential unforeseen costs in the process [62].

4.2. Barriers from the private sector's perspective

The solar PV private sector in this paper includes PV developers, financial institutions, construction companies, consulting companies, and PV suppliers. These companies can have either one or several roles, such as construction, consulting, financing, developing, and providing energy products.

(5) Limited access to capital

The main problem for private companies is limited access to capital. Although there is some financial support from the public sector from state-owned enterprises like Enova, funding is still limited to 35% of the initial cost for installing solar PV [73]. Furthermore, only a few financial institutions willing to invest in solar PV in Norway due to the high up-front investment and uncertainty around achieved electricity output [67]. In addition, the long payback period (usually 25–30 years) discourages investors who look forward to getting money back as soon as possible, as the capital flow and risk guarantees are very important for businesses [17].

(6) Limited pilot PV projects

The annual installed capacity for solar PV in Norway constitutes less than 0.25% of the global market [74], with an installation of 23.5 MW in 2018 [75]. According to a report by Multiconsult, a Norwegian consulting firm, there are few pilot PV projects in the country to learn from Ref. [67]. Limited projects lead to limited opportunities for the industry to learn and develop skills which means that projects are reliant on the expertise of a few individuals may be expensive and difficult to access. Data on PV panel performance, project costs, and benefits gained from existing projects are the basic foundations needed before investing for private companies. However, the reality of limited projects to obtain in Norway leads to a large uncertainty [57], as well as limited experience, knowledge, and solutions on PV development.

(7) Uncertainty surrounding risks

The uncertainty surrounding the risks of investing in solar PV mainly stems from three aspects. First, many investors, including those already involved in a PV project, are not sure how much electricity they will generate [65]. Second, they are not sure about the payback and whether they can find solutions to deal with unforeseen events, such as lower electrical output than anticipated, throughout the whole process [68,76]. Third, private companies are not sure how future policies will affect them because the PV market is still in its early stages in Norway, and the policies and regulations are still changing [67].

(8) Lack of communication among different stakeholders

Communication between different types of actors, such as financial institutions, construction companies, consulting companies, energy companies, skilled workers, and consumers, is required for the development of PV. The reason is that acceptance, understanding, and knowledge transfer are key factors to the diffusion of PV panels early on, which needs to be achieved through communication [77]. However, most actors do not communicate enough and do not know how to transfer their knowledge efficiently [67]. Furthermore, for projects with large volumes of information, lack of communication can lead to failure [77].

4.3. Barriers from the public sector's perspective

(9) Lack of efficient incentives

The Norwegian authorities lack efficient financial incentives to promote the PV market [65]. The existing incentives include a capital subsidy for the initial cost, the right to self-consume, the right to revenues from excess PV electricity injected into the grid, an average loan rate of 3%, as well as a green certificate [56]. However, the initial cost of about 50,000–10,5000 NOK is still high for residents even with the

10–30% capital subsidy. The average loan rate for PV is 3%, similar to the property loan interest, and the green certificate requires a minimum investment of NOK 15,000 (1620 USD) in solar PV, which makes it difficult to get support for small systems [56]. One reason for the low support is that there are conservative politicians with limited knowledge on solar PV, who are unwilling to invest in solar [17].

The results show that many of the barriers of diffusing solar PV in Norway are general and somewhat applicable to many other countries as well, such as high initial cost, limited information and awareness of the possible benefits, uncertainty among people regarding the achieved output, limited access to capital, uncertainty surrounding risks, and lack of communication among different stakeholders. At the same time, there are barriers in Norway which differ from other countries, such as limited financial support policies and models, satisfaction with the current electricity output from hydropower, the uncertainty of the solar irradiation and energy output due to the latitude in Norway, limited pilot PV projects, and the controversy over whether to focus on hydropower or also develop solar energy in the public sector.

5. Discussion

5.1. Potential model in Norway

In this section, the potential of PPPP to overcome the barriers in Norway will be analyzed and compared with the host-owned model, TPO, and CS model.

The above-identified barriers can be classified into three aspects: (1) financial problems, such as high initial cost as well as limited financial support and limited access to capital; (2) information sharing problems, such as limited information and awareness of the possible benefits, low awareness about the solar irradiation and energy output, and lack of communication among different stakeholders; (3) risk and uncertainty problems, such as the risk of extra costs of the PV system from maintenance, risk of misprediction of the actual output, uncertainty of payback time, and changing policies.

For the financial problems, the host-owned model has limited potential. Many householders are not willing to invest in PV because of the high initial cost and low electricity prices in Norway [62]. Although they can get some financial support from the public sector to cover 20–30% of the costs, the cost is still very high [56]. Primarily relying on public financial support as in China is not as applicable in Norway. The controversy over whether to focus on hydropower or to develop solar energy in the public sector makes it unlikely that Norway will invest large amounts in solar PV [71]. The TPO model can solve the high initial cost problem, however, relying on the private sector in Norway is not as suitable as in USA [56]. This is because few pilot cases, lower profitability due to cheap hydropower, and long payback times make it risky for third party companies to invest in solar PV [67]. The CS model has the potential to overcome the barriers by gathering funds from multiple citizens. However, it is difficult to promote the market at this moment, as most citizens have little awareness and information about the benefits of solar PV [65]. The PPPP has the potential to solve the financial problems by combining the resources of all three sectors. It allows the public sector, private sector, and people to divide the high initial costs into more affordable sums [78]. This way, it can attract private sectors through two directions. First, the high initial cost is divided among the three sectors, which will reduce the individual risks for the private sector [78]. Second, projects organized by the public sector are often easier to be convinced, because the public sector has the potential to reduce the risks through policymaking and guarantees [79]. After the investment from both public and private sectors, the remaining amount should be low enough for the citizens to invest in. Finally, by involving all three sectors, the financial support measures from the public sector can be accurately tailored according to the needs of the private companies and citizens, which increases the likelihood that they will be used [80].

The second main problem is about information sharing. The host-owned model does little to spread awareness about available policies and incentives, and the building owners need to find the information by themselves. The third party in the TPO model can take the role of an educator to help citizens understand the benefits. However, the third party is often regarded as an "outsider" and often needs to first establish a trust to lend credibility to their information [81]. The CS model can play a good role in sharing information and transfer knowledge among residents, which allows them to identify the potential benefits and reduce concerns about risk. However, the information is only from the citizens' aspect, as they do not have the same expertise and ability to adapt to unforeseen events as the public and private sectors [82]. The PPPP has great potential for information sharing, as it facilitates the information flow across different sectors, which can improve both the knowledge of PV and the relationship between the different sectors [83]. The information from all the three sectors can give a complete picture for diffusing solar PV. In particular, governments typically have a better understanding of the existing regulations and have the power to make policies to support sustainable energy-related projects [84]. Meanwhile, private companies have a good understanding of the market and can provide expertise in solar PV. Finally, the citizens can provide knowledge about the building situation and their needs, and share new information with their communities [85].

The third main barrier is about risks and uncertainty. The host-owned model has the highest risks among all the models, as the building owners themselves have to fund the main portion of the high initial costs. In the process, any differences between predicted and actual output are their responsibility [86]. In the TPO model, citizens pay a renting fee to the third party, who take the main risks for the citizens and take responsibility for maintenance. However, this only shifts the risks from the people to the private sector [87]. In the Norwegian context, there are already limited pilot cases and related data to study from and limited guarantees from the public sector, which further exacerbate the risk. The CS model can reduce the risks for each individual, but not reduce the total risk of the investment [38]. The PPPP can reduce the risk for each stakeholder by dividing the costs between the three sectors. More importantly, it can also reduce the overall risks by allowing participants to make better-informed decisions based on knowledge from different sectors [88]. The cooperation of three sectors has a better ability to overcome unforeseen events in the installation process, because each sector has different types of experiences and resources, leading to better flexibility than only one or two sectors [89].

In addition to the three main patterns of business models, there are also some advanced innovative business models for the diffusion of solar PV. These models each have the potential to solve one of the existing problems, however, they have limited ability to solve multiple problems compared with PPPP. For example, a new business model was proposed to combine the investment mode and sales mode, as well as designing an interactive consultation service module between supply and demand [90]. An experiment was conducted, which showed that it can enhance the information sharing through consulting services, further promote the local consumption and increase the investors' benefits [90]. However, it is not enough to promote the solar market in Norway at the moment, because it has limited ability to solve the financial problems and risk and uncertainty problems in Norway. Another type of innovative business model emphasizes a revenue-sharing mechanism to promote solar installation [91]. It allows the consumers to get profits directly through transferring the surplus energy to their neighborhood instead of the grid. Its modes include transferring energy between businesses, from businesses to consumers, and between consumers [90]. The sharing between consumers can have the potential to achieve a self-sufficient energy community and reduce the energy loss to the grid [29]. However, it cannot solve the problems related to high initial cost and risks in Norway at this moment.

In addition, Norway has the potential to apply the PPPP. First of all, many stakeholders in the energy sector such as research groups, private companies, and municipalities in Norway collaborate through energy clusters [92]. For instance, the Norwegian Solar Energy Cluster is a solar energy support company consisting of more than 80 industrial partners, major R&D institutions and regional, and national public partners [93]. There are some projects of collaborative energy projects, for example, the +CityxChange project, which explores suitable co-creation approaches to achieve efficient innovative energy systems with joint partners, including public bodies, industries and private businesses, research and academia, and citizens [94]. Furthermore, PPPP is already present in the energy sector, most notably through the prosumer scheme offered by the Norwegian Energy Regulatory Authority [95]. It is a set of regulations supporting cooperation between people, private industry and public sectors, by allowing owners of small installations to sell surplus energy to private energy companies [96].

Second, although the resources from one sector is limited, PPPP can gather the resources of three sectors in Norway. From the people's perspective, the citizens in Norway are likely to engage in PPPP for renewable energy. According to a country ranking of public environmental concern conducted by Franzen and Vogl [97], Norwegians pay much attention to sustainable environmental development, this is particularly exemplified in the electric car industry in Norway which has the most electric cars per capita in the world [98]. Ironically, this has the potential to put stress on the district power grid and if these trends for electric cars continue, there is a need to identify alternative energy sources to avoid blackouts. Solar energy is a viable renewable energy solution as it allows flexibility in supplying to the grid or the household. The desire for a green identity can also attract residents to install solar PV, as it may be seen as a symbol of being modern and progressive, similar to the electric car. The environmentally friendly lifestyle was considered the main driver for households who installed PV panels based on an interview conducted by Winther, Westskog, and Sæle [60]. In addition, according to a survey on the willingness to install PV panels, 56.1% of the survey participants stated that they cared about the electricity bills [62]. In other words, the long-term cost savings for electricity may make people consider installing PV panels.

There are supports for solar PV in the public and private sectors as well. In the public sector, Enova introduced up to 35% support for a range of energy-efficient technologies for households including solar PV. According to a report by Enova in 2008, municipalities are willing to provide support for new approaches that have the potential to promote the diffusion of sustainable energy [99]. The private sector can support the PPPP by providing resources through Norway's strong silicon industry and cheap electricity from hydropower, as well as knowledge and experience from abundant experts and consultants on solar energy. There are also close relationships among different types of private companies. One example is Multiconsult, a consulting company with about 300 experts in the renewable energy sector that provides consulting and design services in Norway.

5.2. Potential solutions with PPPP in Norway

From the perspective of PPPP, the barriers were analyzed, and potential solutions were proposed for the three sectors. Table 3 presents potential solutions for the barriers, and how each group can contribute to a PPPP.

5.2.1. Co-investment with PPPP

A co-investment solution with PPPP can potentially solve financial barriers. Specifically, it can solve the barriers for (1) high initial cost, as well as limited financial support for the people sector; (5) limited access to capital for the private sector; and (7) uncertainty surrounding risks for the private sector.

To solve the problem of (1) the high initial cost for residents and (5) limited access to capital for investors, the basic idea is to expand the existing funding options by reducing the high initial cost to an affordable amount with the three sectors.

This paper proposes a co-investment solution based on PPPP, with investors from the people, private and public sectors to promote a larger PV market. The benefit of including the public sector to co-invest are added investment capital and access to related resources from the public sector. In the long term, if the market for solar PV grows, the public sector can shift governmental funds from subsidizing solar energy to investing in projects [100]. The inclusion of different types of private companies will reduce the investment pressure for the people and public sectors, and they can provide their operational experience on installation, management, making contracts for investing and sharing, problem-solving, and consulting [30]. Finally, the benefits of involving the people are significant, as it considers the citizens' opinions with a bottom-up approach for social sustainability [101]. Besides, citizens' investment for solar PV represents a potentially huge market [102]. As more people participate in this form of co-investment, it will also

Table 3
Potential solutions to identified barriers from a PPPP perspective.

Sector	Main barriers	Potential solutions	What the public sector can do	What the private sector can do	What the people can do
People	(1) High initial cost, as well as limited financial support	Develop a co-investment solution with people, private, and public sectors	Organize a platform to gather investors from different sectors; Create co-investment supporting policies; Co-invest with the people and private sectors	Provide information about co-investment, such as benefits and risks; Make suitable contracts for benefits and risks sharing for co-investing; Co-invest in PV projects	Co-invest with private and public sectors; understand co-investment
Private	(5) Limited access to capital				
Private	(7) Uncertainty surrounding risks				
People	(3) Limited information and awareness of the possible benefits	Knowledge and data sharing platforms across public, private, and people sectors	Provide platforms for different sectors to get information on PV; Provide information and consulting about available policies; Provide risk guarantees	Provide online information and consulting about solar PV from financial, operational, and managerial aspects; Participate in offline platforms for communicating among different sectors, such as meetings, workshops, and presentations	Involvement in different types of platforms, get information about solar PV; Consult with related sectors for specific PV problems; Communicate with other sectors from the citizens' perspective
People	(4) Uncertainty				
Private	(8) Lack of communication among different stakeholders				
Public	(9) Lack of efficient incentives	Design new incentives for solar PV with public, private, and people	Design new support incentives with other sectors according to market needs; Support and testing of new incentives	Design new incentives with other sectors; Provide opinions about desired incentives from a private perspective	Design new incentives with other sectors; Provide recommendations on incentives from a people perspective
Private	(6) Limited pilot PV projects	Encourage the disclosure of existing PV projects information on a platform	Support the development of pilot projects; Share real data from PV projects and their social and environmental impact	Share data on the financial aspect of PV projects; Provide analysis the performance of the existing projects	Provide detailed feedback when involved in PV projects

naturally promote greater diffusion of solar PV. Overall, including investors from all three sectors has the potential to solve the high initial cost problem.

In addition, co-investing with different sectors can reduce the (7) uncertainty surrounding risks for the private sector. A wider base of knowledge and the ability to pool the resources from multiple sectors, can make the partners better equipped to handle unforeseen events during the project [103]. Furthermore, the different sectors can share risks [104].

Aside from solving barriers (1), (5), and (7), the people can get financial and environmental benefits from solar PV through investing affordably and can receive policy support from the public sector and operational experience from the private sector. The private sector can attract co-investors not only from the public sector but also from general residents, which can alleviate the problems surrounding the capital shortage [78]. It can also benefit from the public policies, and possibly provide PV installation services for residents. For the public sector, if the shared model is developed well, they are more likely to achieve their energy goals for 2050 and can help the solar PV industry become more self-sufficient, instead of strongly dependent on the public sector as it is today [100].

5.2.2. Information-sharing platforms with PPPP

The second PPPP-based solution is to design different types of information-sharing platforms both online and offline. The participation of the public, private, and people is required, as knowledge is needed from each group. These platforms can solve the barriers for (3) limited information and awareness of the possible benefits for the people; (4) uncertainty for the people; and (8) lack of communication between different stakeholders for the private sector.

To solve the barrier of (3) limited information and awareness of the possible benefits, an online information-sharing platform with knowledge from the public, private, and people can help citizens obtain and understand information about solar PV [105]. The information should pertain to the financial costs and benefits, electricity output, related incentives, and potential benefits to the local and global environment [106]. Information about financial support and incentives should come from the public sector, while knowledge about the financial costs and benefits, and expected output of solar PV should come from the private sector [107]. The consumers' needs, feedback, and questions should come from the people. With the online information-sharing platform, citizens can easily obtain information on solar PV from reliable sources.

Unlike the barrier regarding limited information and awareness of the possible benefits, (4) the barrier of uncertainty mainly refers to people who already have some interest and understanding of solar PV, but are unsure whether and how to implement it [65]. Therefore, they need a platform for asking specific questions to different sectors, where they can get reliable answers from the relevant sectors.

For barrier (8) lack of communication between different stakeholders in the private sector, the online platform is not enough. Other offline activities to promote the communications among different stakeholders are needed as well. Meetings, workshops, advertisements, and surveys are potential channels to enhance the communication to share the information on PV [108]. Consultants from public and private sectors, who have the relevant knowledge about policies and experience can then clear up any confusion from the citizens.

5.2.3. Creation of new incentive policies with PPPP

The third potential solution is to create new incentives through PPPP that can solve the barriers regarding (7) uncertainty of risks and (9) lack of efficient incentives and policies.

According to these barriers, new incentives and support measures from the public sector are expected to be issued. Furthermore, new incentives should include some risk guarantees, which can ensure that investors will not lose too much. A guarantee can boost sales and increase the confidence of customers, for example, performance guarantee and fixed feed-in tariff [109,110]. In addition, the incentives need to better match the needs of the people and private sectors.

To overcome the barriers, the creation of incentives with the opinions of the public, private and people has been regarded as an efficient approach to consider the needs of different sectors on specific issues [111]. The benefits of creating incentives with PPPP for PV projects can be seen from three aspects. First, it can help the public sector better understand the specific barriers and needs of the private and people sectors [112]. Second, the public sector can evaluate the advantages and disadvantages of new incentives from the perspectives of the participants [113]. Third, incentives designed with PPPP are more likely to get wide support and adopted by the private and people sectors in practice [114].

5.2.4. Co-investment and information-sharing platform with PPPP

Two barriers remain unresolved, namely (2) satisfaction with the current electricity system and (6) limited pilot PV projects. To overcome (6) limited pilot PV projects, co-investment and an information-sharing platform with PPPP are both required. The co-investment will increase opportunities for pilot PV projects, which upon completion can act as proof of viability for future investors. The information-sharing platform will facilitate a comprehensive understanding of the project efficiently. The information should include the financial aspect of PV projects and performance analyses from the private sector, an analysis on the social and environmental impact from the public sector, as well as detailed feedback from people involved in the project.

For barrier (2) satisfaction with the current electricity system, when all the other barriers have been overcome, the benefits of the solar PV will be widely accepted by the public, private, and people, and this will no longer be a barrier.

There are currently no examples of using PPPP to overcome barriers for diffusion solar PV specifically, but there are examples of using it to solve problems similar to the identified barriers related to information sharing. For example, in a case study by Kuronen [115], the application of PPPP was shown to be able to reduce CO2 emissions from residential development by 75% through new system design and newly proposed solutions, by applying knowledge from three sectors and utilize various sectors' resources. The process also gave all the participates a good understanding of the project through information sharing.

6. Conclusion

Research has shown that solar energy has great potential in Norway due to its suitable cold climate, strong silicon industry, and potential energy output from PV in southern parts of the country comparable to that of Germany. However, the cumulative installed solar photovoltaic capacity is still small, and most people in Norway pay little attention to solar PV. This paper highlights the importance of developing solar energy in Norway to meet the electricity demand during winter, provide a more secure supply of energy by diversifying the energy mix, and to protect existing ecosystems which are threatened by the more pervasive hydropower generation.

The adoption of solar PV is influenced by different stakeholders and their cooperation. The different sectors have different concerns about the impact of solar PV on the society, economy, and environment. This paper is the first to classify the barriers for diffusing the solar PV in Norway from the perspective of the people, private, and public sectors. The barriers were explored through a literature review, which identified nine main barriers. For the people, these are (1) high initial cost, as well as limited financial support; (2) satisfaction with the current electricity system; (3) limited information and awareness of the possible benefits; (4) uncertainty, while the main barriers for the private sector are (5) limited access to capital; (6) limited pilot PV projects; (7) uncertainty surrounding risks; and (8) lack of communication among different stakeholders. The main concern for the public sector is (9) lack of efficient incentives.

To explore the potential models to develop solar PV in Norway, the solar PV development, main policies and financial models in different PV leading countries were explained. This paper is the first to analyze the driving sector, financial models, and main form of partnership for the diffusion of solar PV in multiple countries and discuss whether they are suitable in Norway. It was found that the host-owned model, which relies on the public sector, is not an applicable approach in Norway due to the limited support from the public sector. The TPO model is also not feasible, because investment in PV is not as widely accepted in the private sector in Norway due to limited examples of pilot PV projects and limited access to capital for solar PV projects. Finally, the community shared (CS) model is also not suitable for promoting the solar market. The main reason is low acceptance among citizens to invest in solar energy due to limited financial support from the public, satisfaction with the current electricity from hydropower, and uncertainty about the achieved energy output.

After analyzing the identified barriers and the current context in Norway, the public-private-people partnership (PPPP) is proposed to be a partnership form with great potential to promote the PV market. The barriers can be classified into three categories: financial problems, information access and sharing problems, and problems associated with risks. PPPP has a big potential to overcome these barriers, by dividing the high initial costs into more affordable sums, facilitating the information flow among different sectors, and overcome unforeseen events with different types of experience and resources. In addition, Norway is well-suited for the PPPP, as stakeholders in the energy sector such as research groups, private companies, and municipalities in Norway almost always operate as joint groups. Furthermore, citizens in Norway pay much attention to sustainable development and the environment. Finally, there is support for solar PV in the public and private sectors.

To solve the barriers, three concrete measures using PPPP were proposed: a co-investment solution, information sharing platforms, and design for new incentives with PPPP. The co-investment solution with PPPP can solve the barriers for: (1) high initial cost, as well as not enough financial support for the people; (5) limited access to capital for the private sector; and (7) uncertainty of risks for the private sector. Information sharing platforms with PPPP can solve the barriers for: (3) limited information and awareness of the possible benefits among the people; (4) uncertainty in the people sector; and (8) lack of communication among different stakeholders in the private sector. Design for new incentives with PPPP can solve the barriers for (7) uncertainty surrounding risks and (9) lack of efficient incentives.

However, there are also some arguments against developing solar PV with PPPP. First, it will require large amounts of time and energy to organize the different stakeholders on a common platform, as well as persuade them to participate, especially the citizens. According to existing cases with citizens participation, it is quite difficult to engage citizens, due to the financial risks, little decision-making power, and low levels of trust towards outsiders. Second, it will take considerable time to make agreements for sharing the benefits and risks with different stakeholders. Third, there are currently no examples of using PPPP for solar PV, meaning that there will likely be some unforeseen problems. Finally, the communication between the sectors is also challenging, due to the different levels of knowledge in each sector.

With the exploration of suitable policies, models, and partnerships in Norway, PPPP has the potential to overcome existing barriers. Although the solar PV installation capacity is not high at this moment, it likely to grow with increasing awareness and opportunities in the solar market in Norway.

This study has potential limitations. There are currently limited existing resources on solar PV projects, barriers for the diffusion of solar PV, as well as analyses of partnerships for diffusing solar PV in Norway, which may lead to a biased result. Furthermore, while the application of PPPP has been proven to have the potential to make use of more resources, achieve good information sharing and solve the high initial cost problems, there are few real case studies, and its efficiency needs to be further verified. Finally, this paper only discusses the non-technical barriers for the diffusion of solar PV in Norway, which may lead to an incomplete analysis of how to promote solar development.

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Credit author statement

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Declaration of competing interest

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

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