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Analysis of development of Norwegian household solar energy ecosystem

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Analysis of development of Norwegian household solar energy ecosystem

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Abstract. Solar energy for self-production is one of the tools for improving energy efficiency in buildings to achieve EU's climate and energy goals, while solar energy has a very small share and is increasing slowly in Norway. This paper analyses the four main reasons why solar power has an insignificant role: hydropower with much lower cost, low energy output in winter due to less sunlight, unclear personal willingness to adopt solar photovoltaics (PV) on their houses and current fixed PV panels with low energy efficiency. Based on this analysis, we propose to use a tilting PV system for the current buildings to improve the efficiency and performance of utilization of the solar radiation. In three cities Oslo, Stavanger and Trondheim, economic return for the investment in PV panels is also calculated with payback period (PBP) analysis based on the electricity prices in 2022. It shows that it is profitable with the payback period of over 10 years while the solar panels' life span is over 30 years. Further research questions are also discussed.

1. Introduction

With EU's ambition of achieving climate neutrality by 2050 [1], the Energy Performance of Buildings Directive (EPBD) requires all new buildings to meet nearly zero-energy building (nZEB) standard [2]. Improving energy efficiency in buildings is one of the paths to achieving climate and energy goals [3], which gives the floor to solar power for self-production. In Tunisia the research has been done about the assessment of the promising sites to host large-scale solar panels using geographical information systems and multi-criteria decision-making [4]. Some Norwegian researchers have conducted an analysis of the emissions associated with the energy systems of an existing nearly zero-energy university building in a use case scenario [5].

In Norway, although experiments in SINTEF's climate lab demonstrate that solar cells work very effectively despite the rain and cold [6], the data shows there is a slow-down tendency for the increasing installation of solar photovoltaics (PV) systems in this country. According to the Norwegian Ministry of Petroleum and Energy, at the beginning of 2021, the total installed capacity for solar power was 160 Megawatts (MW). During 2020, around 40 MW of new solar power was installed in Norway. This corresponds to the installation of 350 solar panels every day in 2020. The increase was slower in 2020 than in 2019 when the capacity increase was calculated at 50 MW. However, at the end of 2020, about 6.2 TWh of new production capacity was under construction. Of this, 4 TWh is wind power and 2.2 TWh hydropower [7]. Solar energy occupies a small market share and is increasing slowly in Norway. This paper tries to explain the reason for this phenomenon and to find out if it is profitable to invest in household solar panels.

2. The reason of slow development of solar energy in Norway

Solar energy usage in Norway is increasing at a low speed. We take a deep look inside the phenomenon and find out four main reasons: low-cost hydropower, much less sunshine in winter, unclear social acceptance and fixed PV with low energy efficiency.

2.1. Competitive hydropower price

The first reason is that cheap hydropower is the main source of Norwegian electricity production. Hydropower contributed 92 percent of the total electricity production in Norway in 2020, and the Nordic electricity system is therefore highly influenced by the hydrological situation [8].

The price of solar energy has dropped a lot in recent years, while it is still more expensive than hydropower. According to the research of the International Renewable Energy Agency, the price of fixed-axis solar utility scale is 68 US$ per MWh, while the price of hydropower is only 47 US$ per MWh [9]. Especially for Norway, hydropower will be the main source for the power generation in the long run.

2.2. Low energy output in winter

The second reason is that Norway is in a high latitude area and gets very little sunshine for two months in winter. The output of solar panels calculated by the European Union's Photovoltaic Geographical Information System (PVGIS) [10] shows that in Norway the solar input varies from 700 kWh/m^2 in the far north to 1100 kWh/m^2 in the southern parts of the country. This means that one standard solar panel can generate between 500 and 700 kWh of energy each year, given a standard loss of 25% in the PVGIS tool [11].

We take three cities in Norway, Oslo (Latitude 59.913, Longitude 10.739), Stavanger (Latitude 59.102, Longitude 5.713), Trondheim (Latitude 63.432, Longitude 10.405) used for a simulation of output from photovoltaic panels. With the different fixed slope and azimuth at different places in Table 1, the simulation can achieve the monthly maximum energy output in Figure 1. From the data we can see that although the output in December and January is low, the output for the whole year is still significant.

Table 1. Different fixed slope and azimuth for optimization output.

City	Fixed Slope(°)	Fixed azimuth(°)
Oslo	45	2
Stavanger	42	3
Trondheim	44	-1

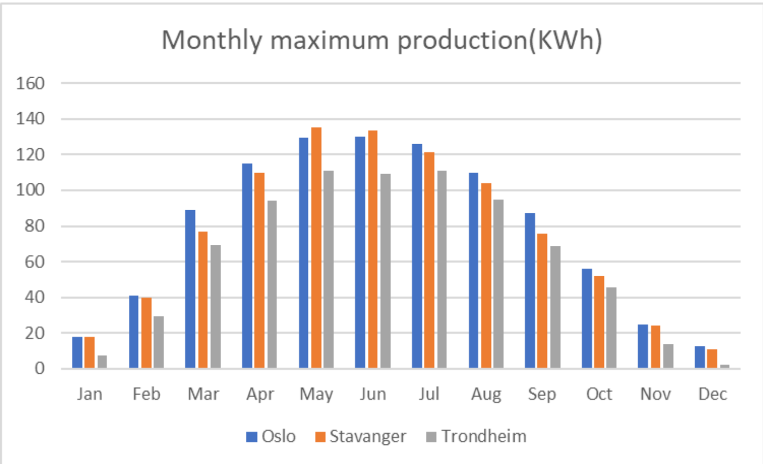

Figure 1. Monthly energy maximum output/m^2 from fixed PV.

2.3. Unclear willingness to adopt solar panels
Solar energy as a renewable energy is environmentally friendly, while there is still a lot of work to do in Norway to target the customers and get social acceptance. This is a question of 'who will adopt'. It is related to the individual willingness to pay, to invest and to adopt solar panels, to make changes to their consumption habits. Hai [12] it shows that different personalities and conditions can determine individual willingness to accept. Personal factors such as motivation and nature of individuals, age, income, occupation, lifestyle, need, knowledge and interest, political, community, market situations can direct people to adopt or not adopt a proposed technology.

In Norway for the Norwegian household solar panels, the houseowners can apply for NOK 750 for the installation and NOK 2000 per KW installed, limited to a maximum of 20 kW, which means that the houseowner can receive a total of NOK 47500 for a 20 KW solar PV installation [13]. However, the total cost of a household PV panel is much more than the support fund. The houseowner, as a rational actor in the market, wants to know if his investment in the household solar panel is profitable. If the investment in the solar panels is profitable, the owner will be motivated to install the PV panels on the roof. Otherwise, it is difficult to persuade them to make an effort. All these factors will influence the potential customers when positioning household solar energy in the Norwegian power market.

2.4. Fixed PV with low energy efficiency
The photovoltaic power generation system installed on the building can be referred to as BMPV - Building Mounted Photovoltaic. BMPV includes two types of solar panel systems: BAPV and BIPV. BIPV refers to Building Integrated Photovoltaic which is designed, constructed and installed at the same time as the building and is perfectly integrated with the building which not only has the function of power generation, but also has the function of building components and building materials. BIPV can't change their direction since solar cells are integrated in the house. BAPV is Building Attached Photovoltaic which is attached to a building, also known as an installed solar photovoltaic building. Its main function is to generate electricity, which does not conflict with the function of the building, nor does it destroy or weaken the function of the original building. BAPV can change their direction according to the sun's direction and height.

Fixed BIPV panels cannot make full use of the sunshine in the effective way because the sun changes its direction during the day and sun height varies much during the year. To create market opportunities for solar energy, BAPV is the feasible solution for the houses and other buildings that are already built up.

3. A solution with the BAPV system
The Norwegian Energy Commission's report published in February 2023 clarifies that Norway needs power expansion of more renewable energy. The report explains Enova aid schemes which aim for energy efficiency for commercial and residential buildings, with time-limited grant or beneficial loan schemes that can help to implement individual measures of energy-efficient solutions including solar energy for self-production in single-family homes and apartment buildings [14]. With the state aid, tracking PV systems may contribute to the goal of energy efficiency in buildings.

On the contrary to the fixed PV system, tracking PV systems can actively orient PV panels to increase the amount of electricity generated by each panel. Therefore, we propose a solution of tilting of the PV panels to make more use of direct radiation and to solve the bottleneck problem of low energy efficiency of fixed PV systems. We use the software Blender 3 to simulate a BAPV system which can tilt in different directions.

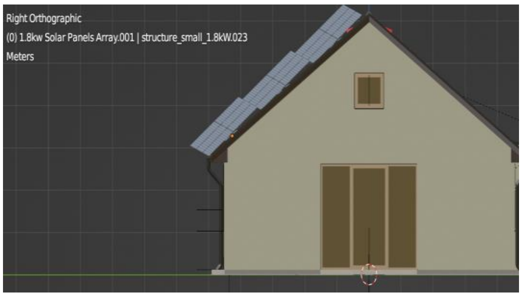

Figure 2. PV faces to the east.

Figure 3. PV faces to the west.

In the morning, the PV panel can turn to the east and face the sunrise in Figure 2. In the afternoon, the PV panel can turn to the west and face the sunset in Figure 3.

Figure 4. PV turns forward in winter.

Figure 5. PV turns backward in summer.

In winter, the PV panel can turn forward to face the sun at low height in Figure 4. In Summer, the PV panel can turn backward to face the sun at high height in Figure 5. In spring and autumn, the PV panels can vary and adjust to the different sun height to achieve the efficiency of the sunshine. This BAPV system is a triaxial sun tracker and the parameters of the BAPV system are shown in Table 2.

Table 2. BAPV module.

Characteristics	Value
Panel dimension (cm x cm x cm)	250 x 200 x 10
Support pole height(cm)	50
Angle of the roof	30°
Range of tilting left and right reference to roof	-21° ~ +21°
Range of tilting backward and forward reference to roof	-26° ~ +26°

4. Economic analysis for the household PV panels

According to the electricity prices in 2022 for end users including grid rent and tax published by Statistics Norway [15], with 1.888 NOK/KWh in 1st. quarter, 2.053 NOK/KWh in 2nd. quarer, 3.176 NOK/KWh in 3rd. quarter and 2.64 NOK/KWh in 4th.quarter, we can calculate the financial income by the output energy in Figure 1 for the household PV panels.

The energy efficiency for the PV systems is 25% which is available for the PV panels in the current market. Therefore, based on the electricity price in 2022, the yearly income from the household PV in Oslo, Stavanger and Trondheim will be 580 NOK/m^2, 554 NOK/m^2, 470 NOK/m^2, as shown in Figure 6.

As to the solar unit price in Norway, solar cell roof plates cost between NOK 2,500 and NOK3,000 per square meter, and solar cell roof tiles cost between NOK 3,500 and NOK 4,000 per square meter [16]. Here we take the investment for PV/m^2 for NOK 6500.

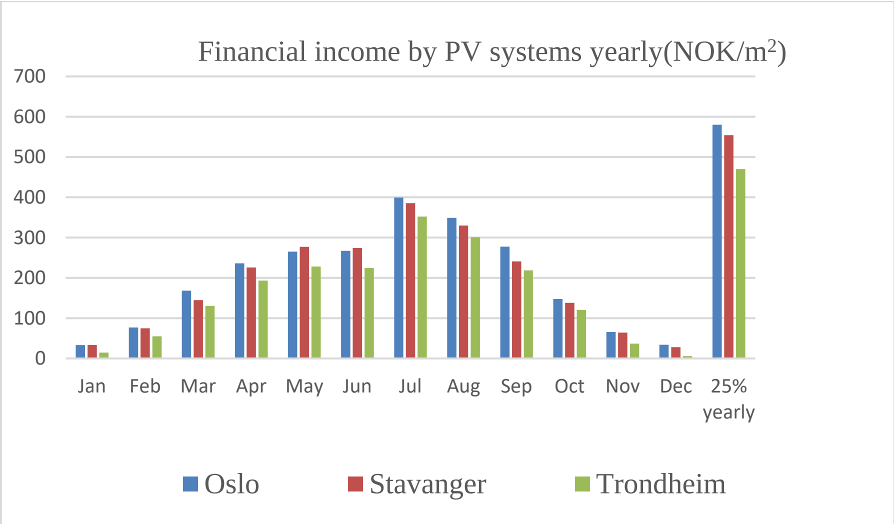

Figure 6. Financial income for the PV panels in 2022.

We use payback period (PBP) method to calculate how fast a household will get back its current cash investment. Payback period is usually measured as the time from the start of production to recovery of the capital investment. The payback period is the time taken for the cumulative net cash flow from the start-up of the project to equal the depreciable fixed capital investment. It is the value of *t* that satisfies the equation below [17].

$$CI = \sum_{t=1}^{T} \frac{\text{Cash flow}}{(1+r)^t}$$

In the equation, CI equals to the current investment; cash flow means income by selling the energy produced by PV panels; and r represents the interest rate of capital. If we simplify that the energy price will rise as the same as interest rate of the capital each year, then we can get a rough number of the payback period of investment in the household PV panels as Table 3 shows.

Table 3. Payback period analysis for investment in household PV panels.

Area	**Current investment**	**Income**	**Payback period**
Oslo	NOK 6500/m^2	580 NOK/m^2	11.2 years
Stavanger	NOK 6500/m^2	554 NOK/m^2	11.7 years
Trondheim	NOK 6500/m^2	470 NOK/m^2	13.8 years

The industry standard for the lifespan of solar panels is about 30 years. However, a solar panel can work longer than their designed life span [18]. That means, the household PV panel begins to make net profit from the 12th or 14th year to the end of its life. This will motivate greatly the house owners to install PV systems from the economic perspective.

5. Conclusion and future work

In this paper we find the reasons behind the phenomenon of low market share of solar energy in the Norwegian power market. Hydropower will still play the main role to generate electricity due to its low cost. Although the solar energy output in December and January is low, the whole year's output is quite significant. The tracking PV system for the houses can be a solution to improve the efficiency and performance of PV panels.

In future, more work will be done on the quantitative analysis of the output of tilting PV panels. Research question will be on how to compare the outputs between a fixed PV system and a tilting PV system under the similar condition, especially the tilting frequency of the tracking PV system since tilting movement brings cost into the scenario. Correspondingly, a further comparison is needed about the different economic benefits between a tilting PV panel and a fixed PV system. If a reasonable forecasting of the future power price is calculated, the net present value (NPV) method will be used for the economic benefit comparison.

References

[1] European Commission: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Youth Opportunities Initiative; European Commission. Luxembourg, 2011
[2] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32010L0031, last accessed 2023/4/3
[3] European Commission. Energy Performance of Buildings Directive. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en, last accessed 2023/4/3
[4] Rekik S, Alimi S E 2023 Optimal wind-solar site selection using a GIS-AHP based approach: A case of Tunisia *Energy Conversion and Management: X* **18**
[5] F.E. Abrahamsen, S.G.Ruud, A. Gebremedhin 2023 Assessing Efficiency and Environmental Performance of a Nearly Zero-Energy University Building’s Energy System in Norway. Buildings **13** 169
[6] Sintef news https://www.sintef.no/en/latest-news/2018/how-well-do-solar-cells-really-work-in-the-nordic-climate/ last accessed 2023/4/3
[7] Norwegian Ministry of Petroleum and Energy report: Electricity Production 2020. https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/#solar-power, last accessed 2023/4/3
[8] The Norwegian Energy Regulatory Authority report: RME National Report Nr. 6/2021, 2021, ISBN 978-82-410-2160-2. https://publikasjoner.nve.no/rme_rapport/2021/rme_rapport2021_06.pdf, last accessed 2023/4/3.
[9] International Renewable Energy Agency (IRENA) report: Renewable Power Generation Costs in 2019. Abu Dhabi. June 2020. ISBN 978-92-9260-244-4
[10] PVGIS homepage, https://ec.europa.eu/jrc/en/pvgis, last accessed 2023/4/3
[11] Berntzen L, Meng Q, Johannessen M, Vesin B, Brekke T, Laur I 2021 The Aggregator as a Storage Provider *11th International Conference on Power and Energy Systems (ICPES)*
[12] Hai M A, Rethinking the social acceptance of solar energy: Exploring "states of willingness" in Finland 2019 *Energy Research & Social Science* **51** 96-106
[13] Enova homepage, https://www.enova.no/privat/alle-energitiltak/, last accessed 2023/4/3
[14] The Norwegian Energy Commission report: Mer av alt - raskere. 01. February 2023
[15] https://www.regjeringen.no/contentassets/5f15fcecae3143d1bf9cade7da6afe6e/no/pdfs/nou2023 20230003000dddpdfs.pdf, last accessed 2023/4/3
[16] Statistics Norway, https://www.ssb.no/en/statbank/table/09387/, last accessed 2023/4/3
[17] Kiran D R, Chapter 22: 2022 Machinery replacement analysis, in the book Principles of Economics and Management for Manufacturing Engineering *Butterworth-Heinemann* 259-267 ISBN 9780323998628
[18] Boligsmart homepage, https://www.boligsmart.no/pris/solcellepanel-tak, last accessed 2023/4/3