INVESTIGATION OF THE FEASIBILITY OF PV ROOF FOR FISH FACTORIES IN NORWAY, PRIMA PROTEIN CASE STUDY.

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ABSTRACT

The primary aim of this study is to assess the feasibility of implementing photovoltaic (PV) roofs in Norwegian fish factories, considering the prevailing weather conditions in Norway to analyze and compare one-year production performance of a 90 KW PV system installed on the roof of the Prima Protein factory. Predicted simulation by HOMER Pro and PV GIS were used to evaluate performance indices such as performance ratio and capacity factor. The study follows a comprehensive methodology that involves calculating the gross roof area using Google Earth and other software, determining the amount of solar radiation, and calculating the PV potential considering the utilization factor and module efficiencies. Following the determination of the potential roof area, PVGIS and HOMER Pro Software are employed to assess the energy production, economic feasibility, and environmental impact of rooftop PV deployment at Prima Protein. The results indicated that the performance of photovoltaic plants is influenced by factors such as roof area, cell technology, and environmental conditions, particularly solar radiation. The annual average energy predicted by HOMER Pro for a 90 KW PV roof system was found to be 89169 kWh/year, while PV GIS predicted a production of 63161 kWh/year, resulting in a difference of 26008 kWh/year between the two software. This disparity is attributed to the influence of cell technology on PV production, the use of different weather data, and the neglect of shadow in HOMER Pro calculation. The capacity factor (CF) of PRIMA PV roof systems was from 10 to 11.7%, this falls below the average CF observed for rooftop PV system in countries with higher solar radiation. On other hand, HOMER Pro economic analysis electricity price result for Prima PV roof is 0.404 EUR/kWh, surpassing the usual electricity price in Norway. Globally, the impact of a PV roof system hinges on various factors, including the specific requirements of the factory, electricity costs, and available installation space. Nevertheless, if implemented and maintained effectively, PV roof systems can offer significant benefits for industrial facilities by reducing energy costs, enhancing energy security, and showcasing a commitment to sustainability and environmental goals. By generating electricity from renewable sources such as solar or wind, industrial factories can enhance their environmental performance and diminish their carbon footprint. According to HOMER results, generating 89169 kWh of electricity from a PV roof system instead of from the average grid mix would avert approximately 507.8 tons of carbon dioxide (CO_2) emissions, 2.2 tons of sulfur dioxide (SO_2) emissions, and 1.07 tons of nitrogen oxides (NO_x) emissions.

1 INTRODUCTION

The industrial sector is responsible for nearly 25% of direct and more than 35% of cumulative global energy-related greenhouse gas (GHG) emissions (Sajid et all, 2022). In Norway, the fish processing industry faces mounting pressure to curtail both its energy consumption and carbon emissions, driven by tightening regulations in the EU energy sector, escalating fuel costs exacerbated by geopolitical events such as the Russia-Ukraine war, and an increasing emphasis on social and environmental responsibility. This study examines the feasibility and conducts a comparative analysis of photovoltaic

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roof (PV roof) installations, based on historical energy consumption and demand data, to lessen reliance on grid-supplied electricity and mitigate CO_2 emissions in fish processing facilities, particularly considering Norway's weather conditions.

Solar PV is growing fast because of dropping PV price, climate change and electricity demand. Installations have surged from 1 GW annually in 2004 to a staggering 150 GW in 2021, despite disruptions caused by the COVID-19 pandemic. Study prediction indicates even more robust growth, with anticipated annual additions ranging between 300 and 500 GW from 2030 onwards, resulting in a total installed capacity of 9.5 TW for solar by mid-century (Energy Transition Outlook, 2022).

We conducted simulations of PV capacity to evaluate yearly production, followed by a comprehensive techno-economic evaluation scrutinizing the technical and environmental merits of PV roof systems. This study employs a rigorous methodology involving the calculation of gross roof area using Google Earth and other software tools, coupled with an analysis of solar radiation data specific to the study location, and the calculation of PV potential, and module efficiencies. Once the potential roof area is determined, we analyze it using PV GIS and HOMER Pro Software to evaluate energy production and environmental feasibility of PV roof deployment at PRIMA Protein. Decarbonization and energy efficiency measures within the industrial sector contribute significantly to sustainable development, environmental conservation, and climate change mitigation (Andersson et al., 2021), (Chen et al., 2020) (Sajid et al., 2019).

2 RELATED STUDIES

Photovoltaic (PV) roofing systems offer a numerous benefit, including clean and renewable energy generation, cost efficiencies, and environmental impact mitigation. Their deployment on rooftops represents a promising avenue for sustainable energy production within industrial settings. However, a comprehensive analysis of both their potential advantages and challenges is essential to optimize their performance and encourage widespread adoption. In the realm of industrial PV power studies, research into roof-integrated PV systems within Nordic climates, as highlighted by (Gullbrekken et al., 2015), has underscored significant challenges related to the installation and ventilation of roofing structures. Addressing these challenges is pivotal for the extensive implementation of PV systems, particularly in specific climatic conditions in Nordic regions.

In their investigation of grid-connected decentralized rooftop PV systems in Sweden, (Ruan et al., 2023) systematically considered various factors such as meteorological parameters, spatial constraints, infrastructure conditions, and economic factors. Their study suggest that PV systems hold substantial promise as a viable option for future power generation, capable of fulfilling a portion of energy demand and alleviating stress on external grids. The rapid development of decentralized rooftop PV systems is attributed to reduce costs, as noted by (Alsafasfeh et al., 2023). (Jiang et al., 2023) conducted a detailed analysis of rooftop PV potential in Jiangsu province, China, demonstrating its significant contribution to total electricity consumption by 30% in the province. Concurrently, (Saini et al., 2023) performed a techno-economic assessment of an innovative hybrid system combining solar thermal and PV technologies for sustainable industrial steam production. Their study showcases the economic viability and land utilization benefits of the hybrid approach.

(Bentouba et al., 2021) assessed the suitability of predictive tools for large-scale PV power plants, with HOMER Pro emerging as a more accurate option compared to RET Screen, PV farm of 20 MW was analyzed in hot regions in Algeria. In the OSTIM industrial zone in Turkey, (Munoz-Rodríguez et al., 2023) emphasized the integration of green roofs with PV elements, resulting in a notable enhancement of energy output. (Ghoroghi et al., 2023) employed a deep learning methodology to optimize energy utilization in fish processing industries, demonstrating significant energy cost reductions. Researchers have developed various methodologies to estimate PV potential in buildings, including sampling, geostatistical, physical, and machine learning approaches. (Gassar and Cha, 2021) provided a comprehensive review of GIS-based estimation approaches specifically employed for rooftop PV potential assessments. Furthermore, (Byrne et al., 2015) explored the feasibility of incorporating PV energy systems into buildings across Seoul, revealing the substantial potential for rooftop-based distributed PV panels to meet a significant portion of the city's annual electrical energy demand. Similarly, (Schallenberg and Rodriguez, 2013) highlighted the substantial energy output achievable

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through utilizing rooftop areas on buildings in the Canary Islands, thereby addressing a noteworthy portion of the buildings' overall electrical energy requirements.

3 METHODOLOGY

3.1 Site Assessment

The PV roof installation is located at Prima Protein in Eiergøy, Rogaland, southwest Norway, with geographical coordinates of 58°45'00" N and 5°58'48" E (refer to Figure 1). The increase in electricity prices, coupled with concerns about climate change and the shift towards green energy, has underscored the feasibility of implementing such a system supported by ROBINSON Project (Robinson, 2024). The energy generated is intended to be fed back into the electricity grid to reduce 10% of PRIMA annual consumption. The geographical positioning of the project, along with local weather conditions, significantly influence PV production.

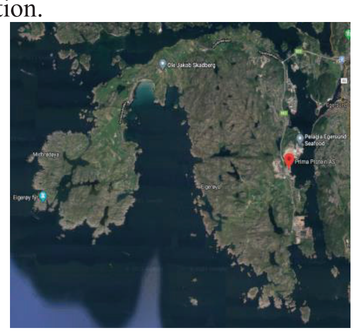

Figure 1: PRIMA factory location

3.2 Evaluate the available roof:

To evaluate the available roof space for the installation of solar photovoltaic (PV) panels at the PRIMA site, we conducted an assessment of five potential areas in the building, as summarized in Table 1. These areas collectively offer a total roof space of 2625 m^2, suitable for PV panel installation. However, for the initial installation, we propose utilizing only 600 m^2 roof space to install a 90 KWp PV system. This approach allows PRIMA Protein to assess the actual production and impact on energy consumption before considering full-scale installation across all available roofs. Additionally, we simulated PV production across all potential areas using HOMER Pro (HOMER Pro, 2023) and PV GIS (PV GIS, 2023) to compare performance. The determination of the number of surface roofs required for the installation of a solar PV system depends on various factors, including the efficiency and size of the PV panels, the orientation and tilt of the roof, shading, and the available installation area.

Table 1: PV feasibility aera in PRIMA

Area in Building (m2)	PV feasibility (m^2)
Area 1: 10 x 50 = 500	500
Area 2: 25 x 55 = 1375	750
Area 3: 25 x 55 = 1375	750
Area 4: 10 x 40 = 400	400
Area 5: 15 x 25 = 375	375
Total Area: 3875	2625

3.3 Estimation of Solar Radiation in Norwegian context weather

Solar radiation estimation is a critical process for determining the solar energy reaching a specific location on Earth. This energy, emitted by the sun and transmitted to our planet, is pivotal for renewable

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energy systems prediction. Pyranometers are commonly utilized for this estimation, measuring solar radiation received at a particular location. Satellite data also contributes to global solar radiation estimation, providing insights into atmospheric conditions like cloud cover and aerosols, influencing solar radiation reaching the Earth's surface. Combining ground-based measurements with satellite data enables accurate estimations, aiding in solar energy system design and climate studies. In Norway, the average daily solar irradiation is 2.46 kWh/m^2, ranging from 0.1 to 0.35 kWh/m^2 in winter and 4.0 to 5.5 kWh/m^2 in summer. Figure 2 depicts the average daily solar irradiation map for January and July. Some southern regions experience solar irradiation exceeding 5.5 kWh/m^2 during summer, making solar energy development not only feasible but also profitable.

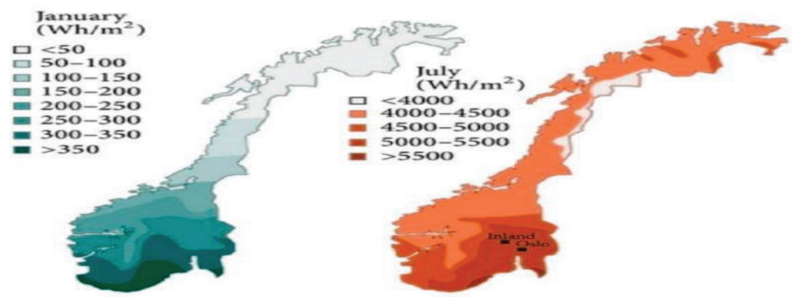

Figure 2: Average daily solar irradiation map of Norway in January and July (Yan et al., 2021)

3.4 Estimation of solar PV potential

Various methodologies have been devised to evaluate the potential of photovoltaic systems in buildings, with some studies proposing methodologies specifically tailored to estimate rooftop solar photovoltaic potential (Peng et al., 2013). The annual PV potential E_{PV} (kWh a^{-1}), considering full PV deployment, is estimated according to Eq and Eq 2 (Peng and Lu,2013):

$$E_{PV}(KWh\ a^{-1}) = A(m^2) \times n_{PV} \times PR \times G \quad (1)$$

where E_{PV} is the energy output of the solar PV, A is the PV area (m^2), n_{PV} is the rated module efficiency, PR is the performance ratio and G is the annual total radiation on the tilted surface (kWh m−2 a−1). In some studies, this equation can be simplified to

$$\text{Size (kW)} = \text{Array Area (m}^2) \times 1\ \text{kW/m}^2 \times \text{Module Efficiency (\%)} \quad (2)$$

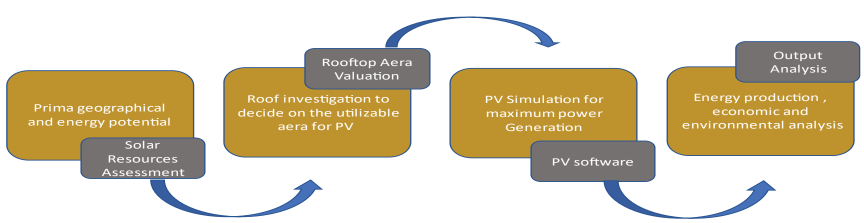

Figure 3: Evaluation process of PV Roof

3.5 Economic analysis

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The Simple Payback method entails calculating the duration required to recoup the initial investment through energy savings. On the other hand, Life Cycle Costing considers the total cost of ownership over the system's lifespan, encompassing maintenance and replacement expenses (Ihsan et al., 2018). The Simple payback is calculated by the following formula:

$$T = \frac{C}{S} \tag{3}$$

where T is the payback period in years, C is the initial investment cost and S is the annual cost savings of electricity that does not need to be purchased.
The life cycle cost analysis has been made to determine the investment cost of the equipment, the operation and maintenance cost. It is used to determine the cost per kilowatt-hour for the PV system. To determine the cost per kWh the following equation is used (Ihsan et al., 2018):

$$\frac{Cost}{KWh} = \frac{Present\ value\ of\ the\ system\ over\ X\ years}{Yield(KWh) genrated\ over\ X\ years} \tag{4}$$

3.6 Capacity factor

The Capacity Factor (CF) of the PV system is defined as the ratio of actual energy generated by the PV system to the theoretical maximum energy output from a similar system operating continuously 24 hours a day. The CF of the PV system can be calculated using the following formula (Bentouba et al., 2021):

$$CF = \frac{\text{Actual output Ac Energy}}{\text{Rated array capacity} * 24 * 365} = \frac{E_{PV}}{P_{rated} * 24 * 365} \tag{5}$$

3.7 Performance Ratio

The Performance Ratio (PR) is a vital metric for evaluating Solar Photovoltaic (PV) system efficiency. It indicates the ratio between the actual yield and the theoretically calculated yield of the system, expressed as a percentage. PR serves as a standardized measure for assessing PV system quality across different locations. It is calculated using the following equation (Bentouba et al., 2021), PR can be calculated using the following equation:

$$PR = \frac{\text{Actual yield (in KWh)}}{\text{Calculated nominated yield}} \tag{6}$$

3.8 Software description

This section provides an overview of the main software and tools utilized to evaluate the performance of the examined techniques. The two software's employed are:
Photovoltaic Geographical Information System (PVGIS,2023): PVGIS is an open-source program specifically designed for photovoltaic (PV) simulation. It is utilized to assess the performance of PV systems and provides valuable information about solar radiation, system output, and related parameters.
HOMER Pro (HOMER Pro, 2023): Developed by NASA, HOMER Pro is a commercial software program widely recognized for its capabilities in modeling and analyzing energy systems. It is extensively used in the renewable energy and microgrid design fields. HOMER Pro enables users to simulate various energy systems, including hybrid renewable energy setups, off-grid systems, and grid-connected systems.

4 SIMULATION RESULTS

The annual electricity consumption of Prima Protein in 2022 has been incorporated into our simulation system to provide a comprehensive understanding of PRIMA electricity demand and PV penetration, as illustrated in Figure 4a (hourly consumption) and Figure 4b (monthly consumption). The penetration is higher in May due to increased solar radiation and Prima Protein's peak consumption during this period. Prima Protein's annual electricity consumption was 66 GWh in 2022.

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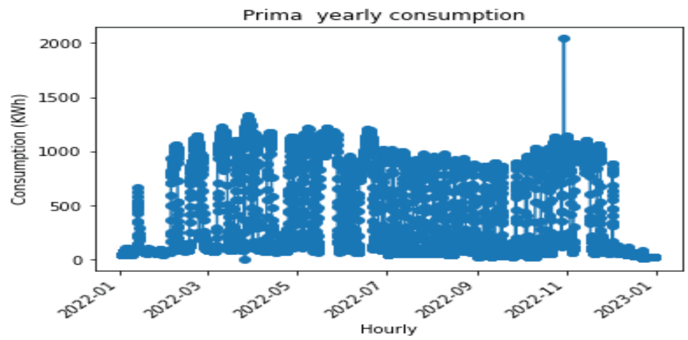

Figure 4a: PRIMA electrical consumption 2022

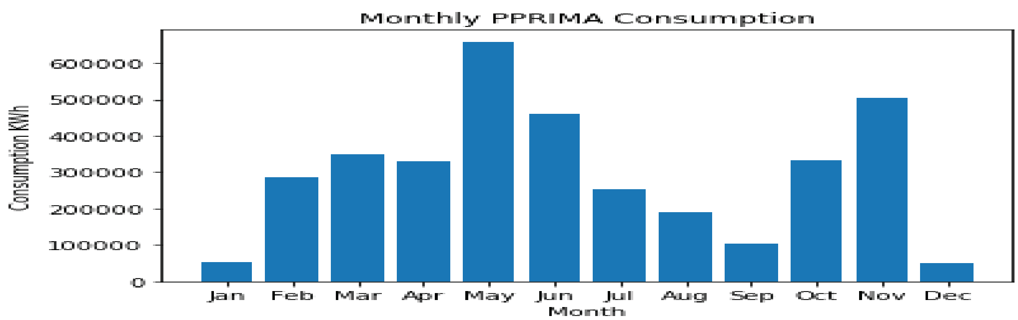

Figure 4b: Monthly PRIMA peak consumption 2022

4.1 PV GIS

Simulation results obtained from PV GIS indicated comprehensive information about solar radiation and photovoltaic (PV) system performance for locations across Europe, Africa, Asia, and America. The energy yield model is validated using measurements conducted on commercial modules at the JRC's European Solar Test Installation (ESTI), an ISO 17025 accredited photovoltaic calibration laboratory (Report IEA-PVPS T13-11:2018). Regarding the average solar radiation at the location, PV GIS utilizes high-quality solar radiation data obtained from satellite images, along with ambient temperature and wind speed data from climate reanalysis models. On the other hand, HOMER Pro utilizes weather data from NASA. In HOMER Pro, the daily average insolation ranges from a minimum of 0.1 kW/m2 in January to a maximum of 0.9 kWh/m2 in July. Meanwhile, for PV GIS, the daily average insolation varies from 0.5 kW/m2/day in January to 5.5 kW/m2/day in July, as illustrated in the figure 5a and figure 5b.

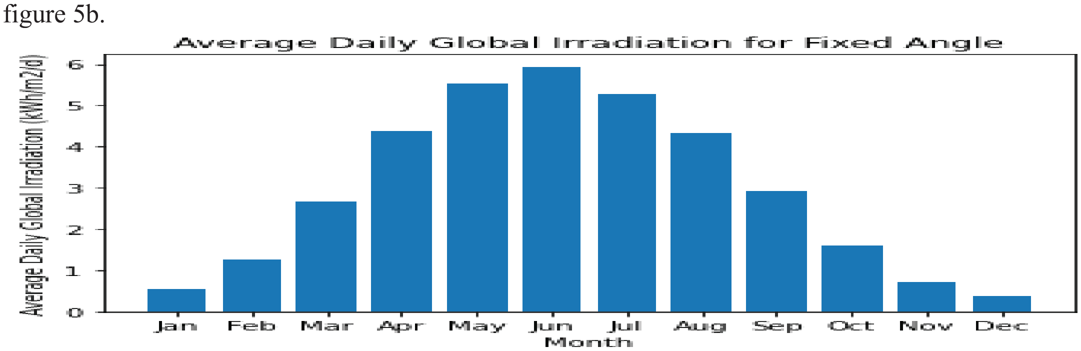

Figure 5a: PRIMA Solar radiation by PVGIS

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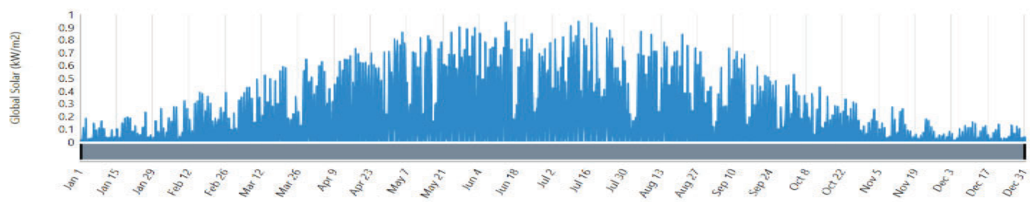

Figure 5b: PRIMA Solar radiation by HOMER Pro

By examining the simulation result figure4 a,b, figure5 a,b and figure6 a,b, we can observe the following trends: Production increases with installed capacity: As anticipated, monthly and yearly production values generally rise with higher installed capacity (kWp). Across all months and the entire year, production tends to be higher for greater installed capacity levels. Seasonal Variation: Notably, there is a discernible seasonal fluctuation in production values. Typically, production is lower during winter months (January, February, December) compared to summer months (May, June, July, August), attributed to shorter daylight hours and reduced solar intensity in winter in Norway. Additionally, performance efficiency of panel technology plays a role in annual production variation. A more efficient PV system effectively utilizes sunlight, converting solar energy into electricity more effectively, thereby enhancing production levels.

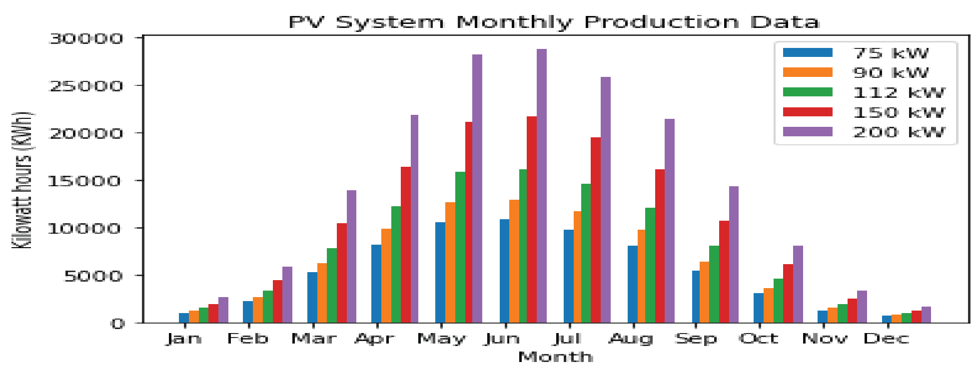

Figure 6a: Monthly PV roof production five scenarios(PVGIS)

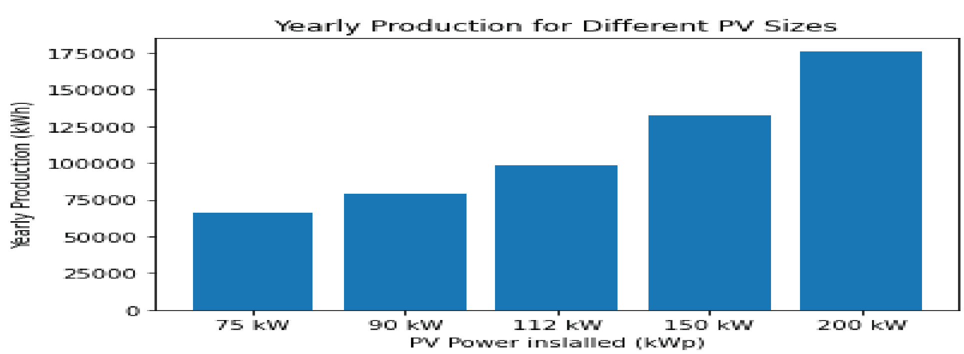

Figure 6b: Yearly PV roof production five scenarios (PVGIS)

4.2 HOMER Pro

HOMER PRO uses configuration system include PV and grid connection as shown in the figure 7.

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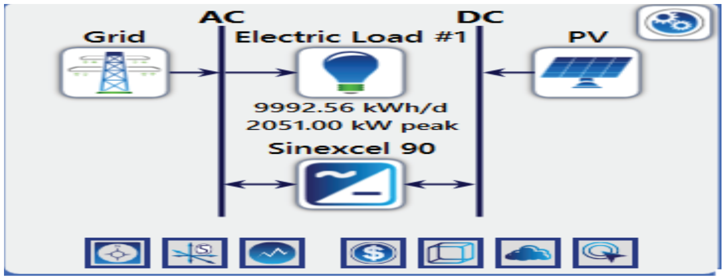

Figure 7: PRIMA PV configuration HOMER Pro

Table 2: Yearly PV Prima production HOMER PRO Scenarios Result

Area in Building (m2)	PV KWp	PV Production KWh
500	75	74947
600	90	89168
750	112	110966
1000	150	148616
1375	200	198148

Monthly PRIMA PV production using HOMER Pro for the five roof scenarios is given in figure 8 and yearly production in table 2.

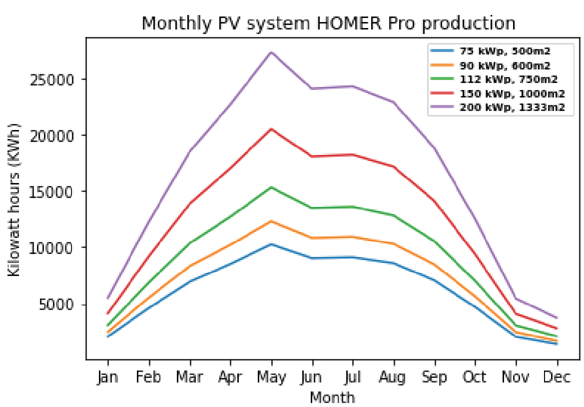

Figure 8: Monthly PV system HOMER Pro production

This production is influenced by factors including the system's size, panel efficiency, roof orientation and tilt, sunlight availability, and temperature. Furthermore, actual production can fluctuate due to weather conditions, time of day, and other variables. The peak monthly production as determined by HOMER Pro is in May (see Figure 8), whereas the peak for PV GIS is in July. This discrepancy arises because the two software platforms use different weather data sources.

5 DISCUSSION

The disparity in annual PV production estimated between HOMER Pro and PV GIS may stem from various factors, including differences in modelling assumptions and input parameters. HOMER Pro utilize more optimistic assumptions regarding PV GIS system performance, such as higher module efficiency or lower shading losses. Additionally, variations in climate data and system design assumptions could contribute to differing predictions. Both tools are reputable and validated, suggesting

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they can offer reasonable estimates for PV production. However, careful consideration of their outputs alongside project-specific factors is essential.

5.1 Environnemental Evaluation

Environmental evaluation examines the sustainability and impact of a project, product, or system. It analyzes environmental factors and their effects, aiding stakeholders in informed decision-making and risk mitigation. PV roof systems can reduce greenhouse gas emissions, air pollution, and water consumption associated with conventional electricity generation. Environmental benefits depend on the region's electricity mix. According to HOMER Pro, generating 89169 kWh from a PV roof system could avoid significant CO_2, SO_2, and NO_x emissions compared to the average grid mix, as shown in Table 3.

The environmental impacts of photovoltaic (PV) installations in Norway are influenced by several factors, including resource use, emissions, and land use. Notably, the environmental footprint of PV systems is often smaller in Norway due to the country's high proportion of renewable energy sources in the electricity mix. Additionally, the lower insolation levels in Norway compared to southern Europe mean that PV systems may have a longer payback period, but they still contribute significantly to reducing greenhouse gas emissions. PV systems can also lead to localized environmental impacts. For instance, the installation process might disrupt local ecosystems, particularly if large areas of land are cleared for solar farms. However, rooftop installations, which are more common in Norway, have a relatively minimal impact on land use. Furthermore, the production and disposal of PV panels involve the use of hazardous materials, although advances in recycling technology are mitigating these effects. Overall, while there are some environmental concerns associated with PV systems, their implementation in Norway is generally seen as a positive step toward sustainable energy production.

Table 3: Environmental evaluation for 90 KWp

Quantity	Value	Units
Carbon Dioxide	507896	Kg/yr
Sulfur Dioxide	2202	Kg/yr
Nitrogen Oxides	1077	Kg/yr

5.2 Economic Evaluation and Playback Period

The HOMER Pro economic analysis electricity price result of PRIMA PV roof is 0.404 EUR/kWh, surpassing the usual electricity price in Norway. In the context of the PRIMA scenario, where the installed PV price is 1,000 EUR/kW and the initial 90 kW installation costs 90,000 EUR, the economic assessment and payback period for this PV rooftop system in Norway unfold as follows: Annual production stands at 89,169 kWh, equivalent to 990 kWh/kW/year. Considering an electricity rate of NOK 1.50 (0.15 EUR) per kWh and an exchange rate of 1 EUR = 10 NOK, the total investment remains 90,000 EUR. Annual savings total approximately 105,300 NOK, comprising 97,200 NOK from self-consumption (80% of total production) and 8,100 NOK from exporting excess electricity (20% of total production, so, the payback period amounts is 8.6 years for PRIMA protein with an installed capacity of 90 kW. Typically, the payback period for a PV rooftop system in Norway spans from 8 to 15 years, contingent upon factors such as installation costs, solar irradiance, electricity prices, self-consumption rates, and available incentives. Despite the substantial initial investment, the promise of long-term savings and environmental advantages renders PV systems an appealing choice for numerous Norwegian households.

5.3 PV Plant Performance Analysis

The capacity factor (CF) of PRIMA PV roof system ranges from 10 to 11.7%. This falls below the average CF observed for rooftop PV systems worldwide. For instance, CF values in other regions are notably higher, such as 20% in Algeria, 16–17% in India, (Bentouba et al., 2021). The CF of the system is primarily influenced by the Global Horizontal Irradiance (GHI) at the location of the PV system and

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the cell efficiency of the PV modules. The feasibility of PV roofs in Norway's conditions has been established, given the generation of sufficient electricity in kWh/kW/year. However, this generation is notably lower when compared to other regions worldwide. On other hand, the performance ratio varies between HOMER Pro and PV GIS based on the weather data and parameters of each software as indicated in the table4.

Table 4: HOMER Pro and PV GIS Result Performance

PV roof (KWp)	Prima Grid Purchases KWh	PV Penetration %	CF % HOMER	CF % PV GIS	PR % HOMER	PR % PV GIS
75	3577437	2	10.7	10.35	92.35	81
90	3564077	2.44	10.7	10.40	91.56	81.35
112	3545142	3.04	11.3	10.49	91.16	80.99
150	3514556	4.06	11.39	10.42	91.56	81.35
200	3478153	5.39	11.7	10.42	91.58	81.37

Norway's dependence on hydropower and wind power is 98.4% (Statistics Norway, 2024), contributing significantly to its clean and renewable energy portfolio. However, integrating photovoltaic (PV) plants into the energy mix can further diversify renewable energy sources and improve energy security. PV plant performance analysis adheres to the standards set by the International Electro-technical Commission (IEC) 61724. These standards outline a comprehensive procedure for assessing the performance of various PV systems, including standalone, grid-connected, and hybrid setups. Key performance parameters such as energy output, array yield, final yield, reference yield, PV module efficiency, inverter efficiency, system efficiency, energy loss (array capture loss and system loss), performance ratio, and capacity factor are evaluated. By adhering to these standards, stakeholders can ensure accurate performance assessment and optimize the efficiency and reliability of PV systems.

6 ROBINSON

The Prima PV roof system was evaluated in context of Robinson project n 957752 (Robinson, 2024): Smart integration of local energy sources and innovative storage for flexible, secure, and cost-efficient energy supply on industrialized islands. It was based on all locally available sources in combination with the existing cable connection to the mainland with the goal to avoid a costly additional or extended sea cable. The concept is visualized in Figure 9.

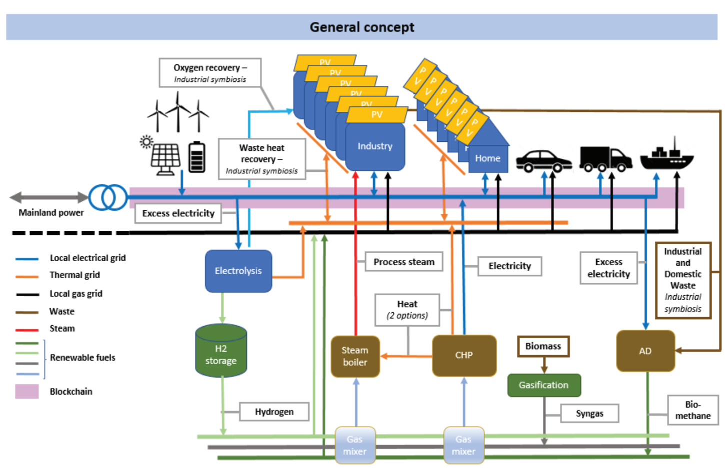

Figure 9: Robinson concept Smart integration of local energy sources and i storage for flexible

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7 CONCLUSIONS

In conclusion, the implementation of PV roof systems in industrial factories presents several advantages, including renewable energy generation, improved environmental performance, and potential cost savings. The economic viability of PV roofs is increasing due to falling technology costs and potential government incentives. Furthermore, PV roofs play a vital role in reducing CO_2 emissions by replacing fossil fuel-based electricity generation with clean and renewable energy sources, aligning with EU sustainability goals. PV roof in industry contribute also to energy reduction and efficiency in fish factories by decreasing reliance on conventional grid electricity, leading to lower energy consumption and cost savings. Additionally, PV roofing systems help and balance the grid by providing decentralized electricity sources and boosting grid resilience when coupled with energy hybrid solutions. Finally, PV roofing systems in Norwegian fish factories offer a comprehensive solution, providing environmental sustainability, grid stability, and economic benefits, supports job creation in the renewable energy sector, and combatting against climate change. This support EU environmental efforts by promoting sustainable energy practices and green transition. However, it's crucial to consider drawbacks such as intermittency, low-capacity factor in Norway compared to the south of EU, space limitations, and reliance on weather conditions when considering PV roof installation.

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