American University Kyiv

A Capstone Project

STRATEGIC MANAGEMENT OF SOLAR ENERGY SYSTEMS IN UKRAINE: CHALLENGES AND OPPORTUNITIES IN A TRANSITIONING ENERGY MARKET (CASE STUDY OF AN ENERGY BUSINESS UNIT)

СТРАТЕГІЧНЕ УПРАВЛІННЯ СОНЯЧНИМИ ЕНЕРГЕТИЧНИМИ СИСТЕМАМИ В УКРАЇНІ: ВИКЛИКИ ТА МОЖЛИВОСТІ НА ПЕРЕХІДНОМУ ЕНЕРГЕТИЧНОМУ РИНКУ (ДОСЛІДЖЕННЯ НА ПРИКЛАДІ ЕНЕРГЕТИЧНОЇ БІЗНЕС-ОДИНИЦІ)

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TABLE OF CONTENTS

ABSTRACT

After intense attacks from russia in the summer of 2024 more than two-thirds of the energy capacities in Ukraine were destroyed, leaving the Ukrainian energy market suffering from constant power outages and needing to find funding to restore deficient energy. The purpose of this work is to examine the potential of solar energy systems (SES) to mitigate the challenges that Ukraine is facing because of the impact of the war, as well as their benefits in the long-term perspective for fulfilling the goals like energy independence, economic recovery, and environmental sustainability.

This research utilized a mixed study approach. The quantitative analysis method was used to analyze the case studies of SES installations in Oleksandrivka, Kherson region, and Tetiiv, Kyiv region, while qualitative method was used to examine the current trends and policies to better understand the gaps that prevent rapid development of Ukraine's green energy market.

Based on the findings, Ukraine's energy system can benefit from hybrid renewable energy systems (HRES). Despite having high initial investments, the benefits such as a decentralized energy system, low maintenance and operational costs, and low environmental impact make this technology very advantageous both for Ukraine's fast recovery and long-term stability. The analysis of cases revealed that SES projects without storage systems could achieve a return on investment within 3.5 years, with capital expenses (CAPEX) costs declining by 27% over the past five years. Additionally, both photovoltaic systems and energy storage solutions were found to be highly financially viable.

To promote the development of SES in Ukraine, a cohesive strategic framework should be implemented. It is needed to facilitate the procedure of regulatory needs such as building permits and grid connection approvals and create a safe investment environment for both local and foreign investors. Moreover, the state should undertake measures for grid modernization and recovery with a view to facilitating the connection of new power plants to the general grid. Stimulation of development of energy storage units and creation of regulatory environment for energy balancing businesses would provide significant long-term benefits for the country's energy independence and stability. By addressing these problems even higher growth rates of new SES installations could be expected, enhancing Ukraine's energy resiliency.

Keywords: energy sector potential, renewable energy, SES, energy security, sustainability.

INTRODUCTION

Since 2022, Ukraine has faced some tragic consequences from the war. Among them, is the so-called "Energy crisis" that impacted the economy and the daily lives of civilians and businesses. Indeed, the generation was disturbed by the destruction of the Ukrainian production capacities and grid, and the supply could not meet the country's needs, creating black-out situations on a daily basis. Those black-outs create constant losses for the country, in a period where the dynamism should be kept at all costs.

To mitigate this problem, some solutions have to be found immediately, but meet as well the question of the long-term vision of the country. Indeed, Ukraine took part in the Paris Agreement and set targets of not exceeding 60% of greenhouse gas emission levels of 1990 by 2030 (United Nations Framework Convention on Climate Change (UNFCCC), 2021). Those agreements could be seen as a heavy burden for Ukraine that needs fast solutions, without losing the aim of meeting the expectations of the European Union. Since Ukraine always strongly depended on nuclear energy and gas, it is a whole new model that has to be designed but still needs to be efficient, affordable, and profitable. This whole new model implies a new grid design and geographical organization.

Already since 2014, the researchers were talking about the implementation of alternative energy sources, photovoltaic systems in particular, because of the rapid development of this technology as well as decrease in cost of such systems (Borokhov, 2014; Kharlamova et al., 2016). The idea of becoming energy independent was popular at the time, since the initial invasion of russia in Ukraine in 2014. (Onyshchenko & Sivitska, 2014). Nowadays, becoming energy independent is not only the question of modernization of the energy sector, but also survival, due to the significant destruction of power plants during russian-ukrainian war (Sabishchenko et al., 2020; Kubatko et al., 2023). In addition, Ukraine has a huge potential for SES, with implementation of which it would be very beneficial for common European goals of achieve sustainability (Trachuk, 2023).

While prior studies (Onyshchenko et al., 2022; Trachuk, 2023; Sabishchenko et al., 2020) highlight the potential of SES in Ukraine, there remains a lack of comprehensive research addressing the integration of SES into Ukraine's energy market, particularly in the context of damaged infrastructure and energy security concerns. This study addresses these gaps by examining the challenges and opportunities for SES adoption in Ukraine. The purpose of this study is to show that SES can serve as a crucial element of Ukraine's energy transition by providing a sustainable alternative to traditional energy sources. Specifically, the research will:

1. What are the innovative solutions in SES that could be applied to the Ukrainian context?
2. Could solar energy systems fulfill the needs of missing electrical capacities?
3. What are the long-term effects of the adoption of this type of green energy?

To answer these questions a mixed-method approach was used to analyze the data used for this research. Quantitative methods include data forecasting and financial modeling, which assessed SES feasibility by comparing capital expenditures (CAPEX), return on investment (ROI), and energy production metrics. Qualitative methods included analysis of insights from other researchers and policymakers to better understand Ukraine's specific socio-politic and economic landscape for SES integration.

For this study two solar power plants were selected. Oleksandrivka in the Kherson region and Tetiiv in the Kyiv region. Oleksandrivka is located on the south of Ukraine, where there is the highest insolation on Ukraine's territories, which shows country's solar energy potential. On the other hand, Tetiiv is located in a more central region, with moderate rates of solar irradiation and high urban and rural energy demands. These SES were chosen for their geographical, climatic, and infrastructural diversity. Analysis of solar stations in these locations would give a comprehensive overview of the feasibility of this type of energy production and provide with general challenges and opportunities of applicability of SES solutions in other regions in Ukraine. The purpose of this study is to understand whether or not solar energy stations are a good fit to be installed nationwide.

The paper is organized into four sections. First, it examines Ukraine's current energy sector, focusing on the challenges posed by war and reliance on non-renewable resources. Second, it explores technological innovations and solutions for SES integration. Third, it evaluates the socio-economic value of SES through case studies and financial analysis. Finally, the paper concludes with strategic recommendations to support Ukraine's energy transition and resilience in the face of conflict.

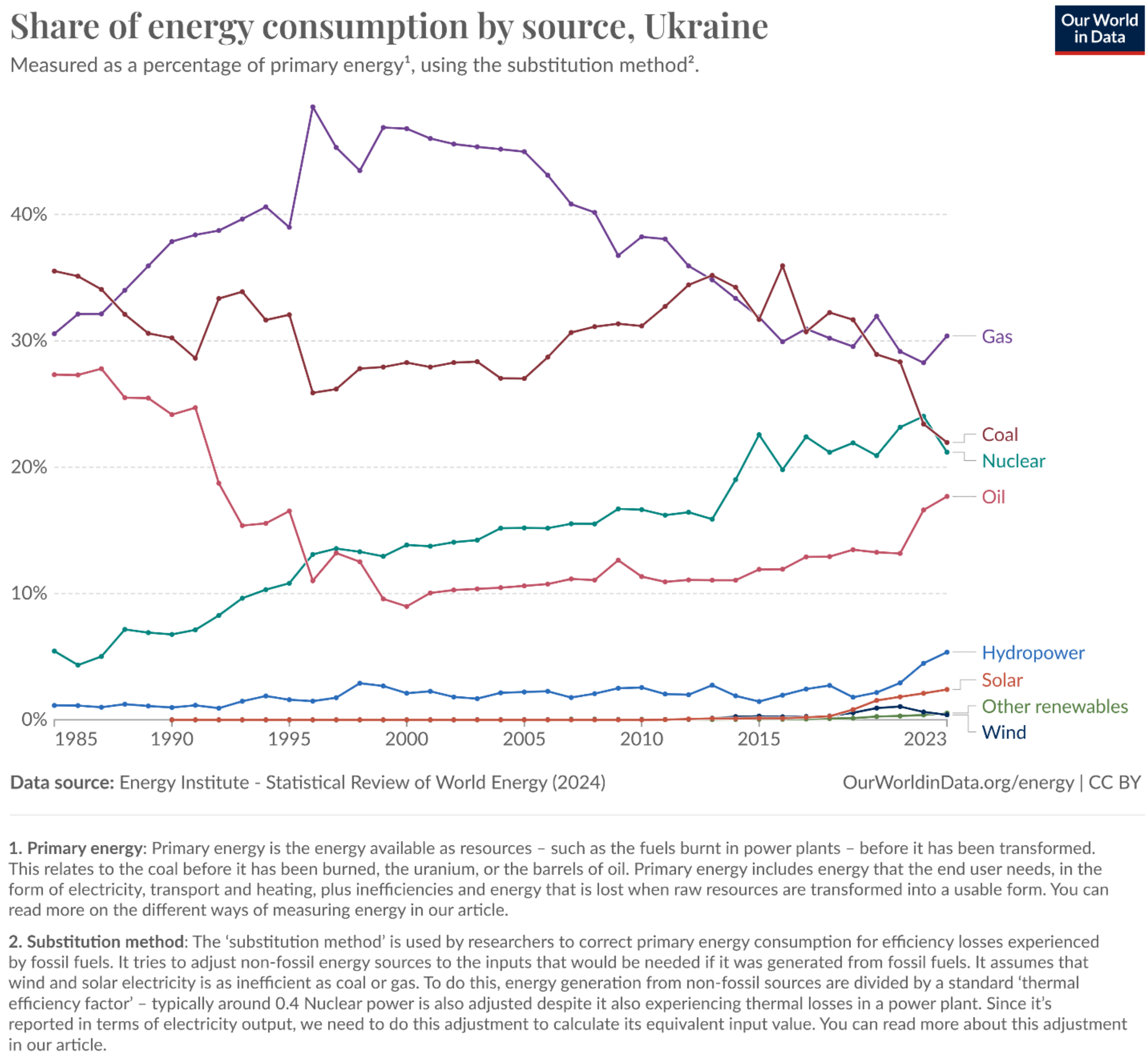
CHAPTER 1. REVIEW AND ANALYSIS OF THE CURRENT ENERGY SECTOR IN UKRAINE

1.1. Ukraine's Energy Mix

To better understand the current situation in Ukraine, a comprehensive examination of the different sources of energy production in the country was conducted, as well as the changes that the industry has undergone in the past two decades. The country's energy mix nowadays includes nuclear, coal, natural gas, oil and a growing share of renewable energy sources such as solar, wind, hydropower, and biofuels. Since primary energy consumption includes electricity, heat, and fuels for transportation, and the purpose of this work is to understand the impact of photovoltaic systems on the industry, this work will focus mainly on electricity production.

Ukraine's share of energy consumption looked completely different 20 years ago from what it is now (Graph 1). The share of coal and gas was more than 70% in the overall energy mix with coal having a share of around 27-28% and gas 45%. At the same time, nuclear contributed around 15%, oil provided 10%, and renewable energy sources granted only a minor share in the mix, which mostly consisted of hydropower energy. However, there has been a significant change in the share of energy in the past 20 years due to the political, economic, and environmental factors.

In 2014 Ukraine for the first time since being independent faced the aggression from russia, which let to annexation of Crimea and occupation of eastern Ukraine territories which were rich on fossil fuels. Because of the neighbour's action Ukraine was forced to look for alternative energy sources. Gas shares started to drop because of the unrealistic prices that Russia was demanding and contract conditions that led to so-called "gas-wars". In 2015 Ukraine fully stopped imports of gas from Russia relying only on own production and European supplies. To substitute for the lack of energy that the energy industry faced, the development of nuclear energy production started siring rapidly. Unfortunately, the biggest nuclear power plant was occupied by the occupants which led to the decline of the energy production from this source. Another big change that began in 2018 is the introduction of renewable energy sources to the mix. Because of the government incentives like "green tariff" and decline in prices for renewables technologies, 2019 became a year when significant amount of solar and wind stations started to open. To sum up, although still highly dependent Ukraine was moving towards reducing the use of gas, coal and oil. In pre-war conditions, in 2021, gas and coal contributed less than 60%, nuclear reached 25% of the energy production, and renewables became 6,2% in comparison to 3,3% of the energy mix in 2018.

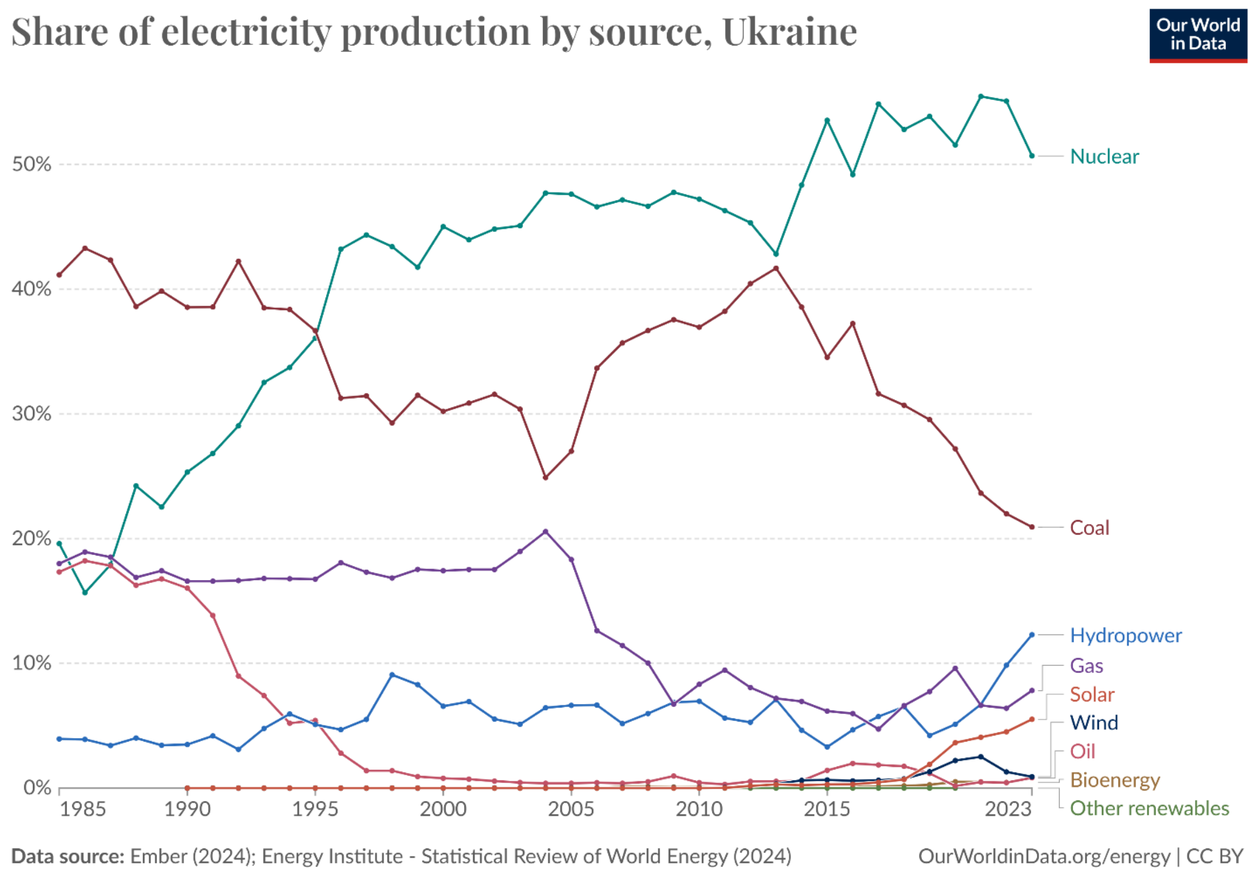


Graph 1. Share of Energy Consumption by source, Ukraine

Source: Energy Institute - Statistical Review of World Energy (2024)

When it comes to electricity production nuclear energy has obtained its leadership in 1995, and although precise statistics have become harder to obtain since the start of the war because of closed official statistical data due to security reasons, nuclear energy remains the dominant source of energy generation in Ukraine and accounts for more than 50%.

As it was mentioned in the previous section because of "gas wars" with russia the usage of the gas was dropping rapidly since 2005. As can be seen from Graph 2 coal was used to compensate for lack of electricity production. However, since 2014 we can see a significant decline in coal usage because of the occupied territories of Donbas region. In addition to forced circumstances, solid fuel has some logistic costs and issues. In a coal or biomass power plant, for example, daily deliveries of hundreds of tons of fuel are needed, creating a complex situation and difficult supply processes creating dependency on third parties and distribution. Certain power generation methods, such as solar panels are more passive, requiring minimal maintenance, low operational effort, and reduced costs. While similar to wind energy production, solar energy is generally considered more predictable and less intrusive. Efficient energy generation depends on predictability, which is essential for ensuring reliability. Uncertainty brings a lack of balance and eventual disturbances in the market, eventually resulting in consequences for households or industries.



Graph 2. Share of electricity production by source, Ukraine

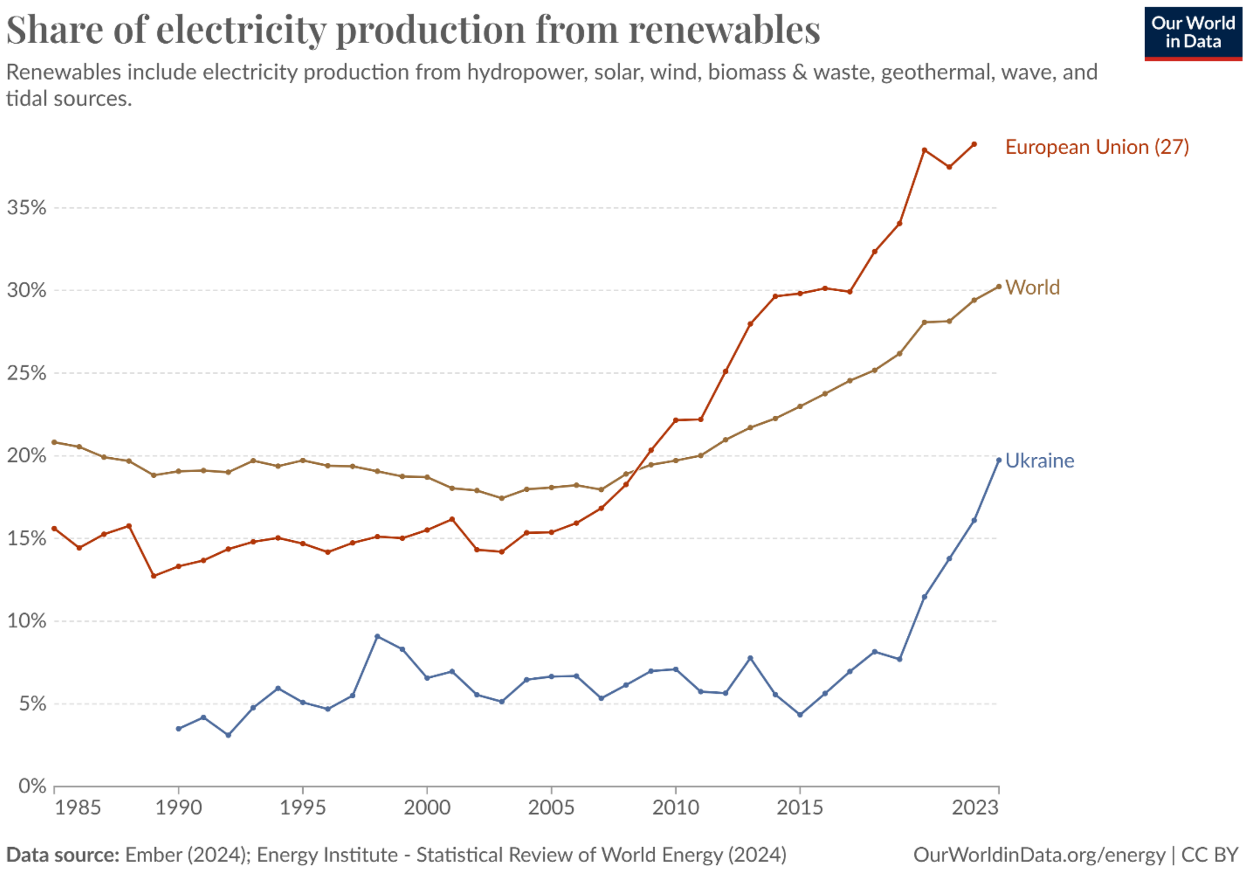
Source: Ember (2024); Energy Institute - Statistical Review of World Energy (2024)

Another factor that influenced the change in sources of energy production is the global trend for lowering greenhouse gas emissions. Ukraine, like many other countries, signed the Paris Agreement, aiming for climate change mitigation. According to the International Energy Agency (IEA), Ukraine's share of renewable energy in the total energy generation in 2022 was 12% (IEA, 2024).

The dynamics of renewable energy share in Ukraine's energy mix has been following the global trend, even exceeding it. Since 2018 the average annual growth rate for the production of energy from renewables was 27%, which was caused by installations of SES and HES. The share of the electricity production from renewable sources in Ukraine was around 16% in 2022, whereas Europe reached a level of almost 40% (Graph 3).

The reason for this global trend is the technological advances making the generation of green energy simpler and cheaper. Combined with the green tariff provided by the Ukrainian government, locking the purchase prices, it became a profitable and safe investment with a positive impact on the energy independence of the country. Some other international agreements and targets helped the global trend to follow the direction. As an example, the Paris agreement has been adopted by 196 parties during the UN Climate Change Conference.

In terms of costs, according to the IEA, solar panels are one of the cheapest renewable energy sources, making it easier to invest in (IEA, 2024). The price is expected to go even lower with time, since the technology and the mass production of those modules coupled with technical innovations, make it even more accessible.



Graph 3: Share of primary energy consumption from renewable sources

Source: Ember (2024); Energy Institute - Statistical Review of World Energy (2024)

1.2. Current challenges and infrastructure

Connecting new sources of energy is not always simple or compatible, coming with high costs for new infrastructures. Although Ukraine's power grid has demonstrated efficiency in the past, it has been severely damaged, leading to significant instability in energy distribution. According to the United Nations Development Programme (UNDP), over 10 billion US dollars of damage were caused to Ukraine's energy infrastructure already in April 2023, by repeated attacks from the russian federation (UNDP, 2023). In the list of concrete examples, the Trypilska TPP can be found, the former biggest thermal power station that had a total capacity of 1,800MW.

Significant investments are required to update and repair the system and connect it to new generation methods. For example, district heating needs networks of heat pipes connected to thermal plants like biomass or coal in order to transport it to housing residences, plants, etc… to a district heating central utility plant. A plant can therefore not be built in a random location, because it is highly dependent on this network. Given Ukraine's crisis, urgent solutions are required to address immediate energy needs while preparing for a long-term transition.

An important point to take into consideration is the adaptation of the production to local assets/resources. A biomass power plant for example needs some supply capacities of wood in a short distance, meaning preferably in the west/northwest of the country.

Figure A. Forest ratio by administrative regions

Source: (Kitsoft)

This example applies to the coal power plants as well, and the location of the coal mines, strongly concentrated in the East (occupied) parts of the country.

A key advantage of solar energy is its independence from physical fuel supply chains, relying solely on sunlight as a resource. In order to connect to the grid, solar farms usually need several steps to be checked. First of all, location should be studied as mentioned (considering the location's solar irradiation levels and proximity to the grid), and the grid should also be able to handle this additional power coming from the solar farm. Given the intermittent nature of solar power, fluctuations must be mitigated through measures such as energy storage to ensure stability. Obviously, additional equipment is needed, such as an inverter, to convert direct current (DC), into alternating current (AC) that is compatible with the grid.

To give precise data about those needs of infrastructures, it has to be considered that 10 billion USD worth of repairs are needed to reestablish Ukraine's former grid. On top of that, Ukraine aims to develop a new grid compatible with the European Union's system, aligning with its application for

EU membership and fostering strategic partnerships with European allies. By becoming part of the Energy Community in 2011, Ukraine already showed its aim to comply with the European energy market and regulations. This strategic full membership shows some very positive effects for Ukraine since the Ukraine Support Task Force (USTF) has been established there.

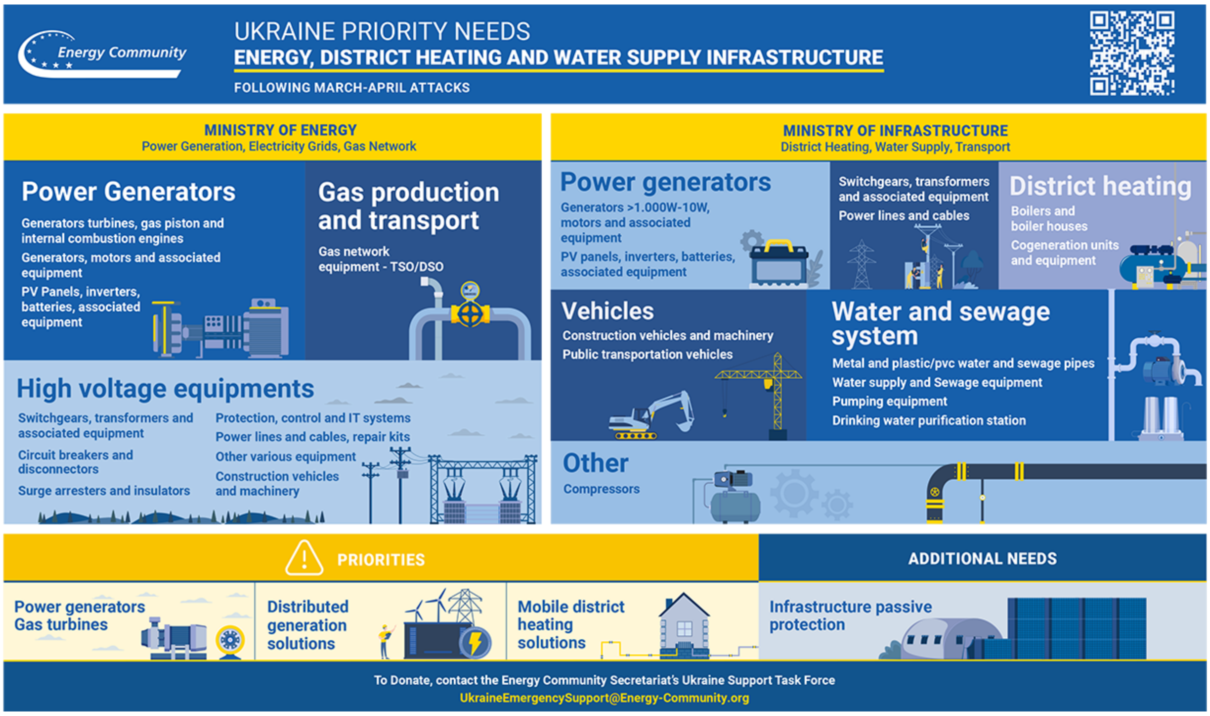


Figure B. Ukraine priority needs

Source: Ukraine Support Task Force

"Ukraine experienced an acute power deficit over the summer months of 2024, when its generation capacity fell 2.3 GW below its peak demand of 12 GW, despite electricity imports from Ukraine's western neighbours" (IEA, 2024).

1.3 Ukraine's Power capacities pre-war vs after war

According to the Royal United Services Institute, Ukraine had an actual power generation of around 25GW and is now reduced to approximately 9GW (Watling & Dolzikova, 2024).

A large amount of Ukraine's power generation came from its nuclear power plant, one of them being in an occupied zone, it has faced several drastic changes. Since 2022, Ukraine has lost operational control of the Zaporizhzhia Nuclear Power Station, now managed by russia's state nuclear company, Rosatom. This loss was not the only one: since the start of the invasion, Ukraine lost many installations in currently occupied or conflict zones. Various facilities, including solar farms, wind farms, and coal power plants, have been either destroyed or seized by russia, disrupting Ukraine's energy balance.

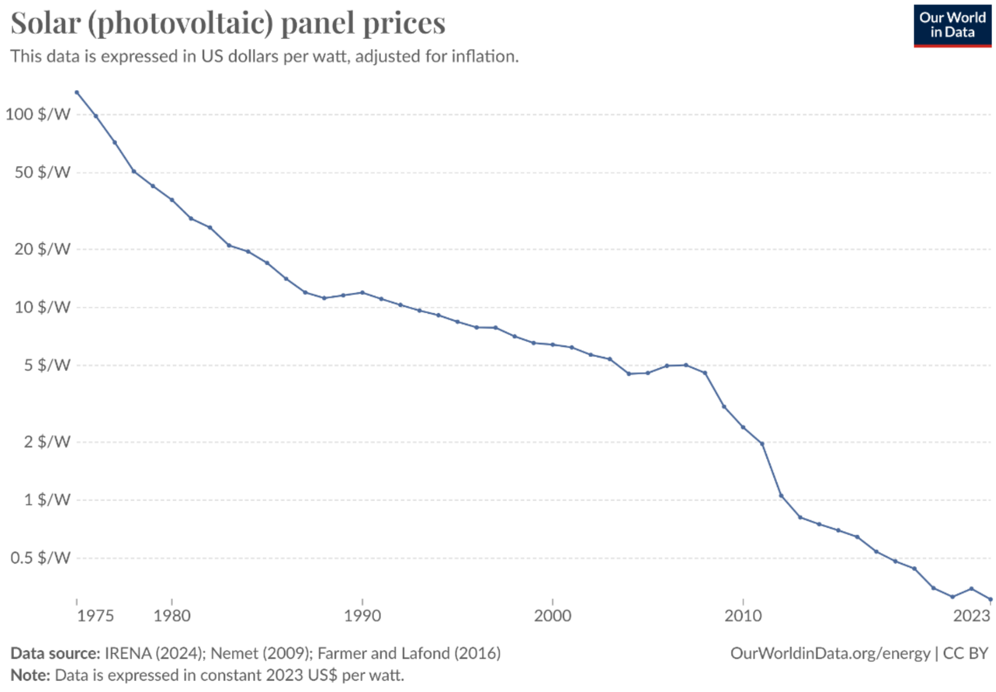
CHAPTER 2. INNOVATIVE SOLUTIONS OF SOLAR PANELS: OPPORTUNITIES AND CHALLENGES FOR UKRAINE

The Sun is the biggest energy source in the world. It produces enough energy to supply the whole world with electricity. In addition, as solar physicist Pål Brekke said “The Sun is an almost inexhaustible source of energy” (Statkraft, 2022). So why not use it as a main source of energy production? In this section, the advantages and disadvantages of such a method of energy production, and what innovative solutions are present on the market would be explored.

The green energy market does not stay in one place. Nowadays, there is an abundance of different solar panels available for both private and industrial applications. In recent years the demand for cleaner energy has risen rapidly. There are a couple of good reasons for that.

2.1. Drivers of Solar Energy System Development

The European Commission with the approval of The European Green Deal has made it its goal to transform the European Union into a climate-neutral zone. Such governmental incentives are designed with the objective of reducing CO_2 emissions, thereby mitigating the impact of global warming and pollution. Still, in 2022, almost 40% of the electricity production in Europe came from oil, coal, and gas, the types of materials that have the highest rates of pollution.



Graph 4. Solar panel prices

Source: IRENA (2024); Nemet (2009); Farmer and Lafond (2016)

Another factor that led to the development of photovoltaic systems is the unstable and high prices for combustible primary energy sources. Not only does the dependence on resources involve the largest amount of expenditure for the countries, but it also gives an element of power to the suppliers of those resources. So, the prospect of using technically “free” solar energy that gives more geopolitical safety is very appealing.

And lastly, the market of photovoltaic systems became very saturated with different players, which made the competition higher. Such rivalry of competitors boosted the research and development of new solutions for this market, to keep the product competitive, as well as lowered the price for this technology. As demonstrated in the graph below, a decline in solar panel prices by 62% has been observed over the past decade (2023 vs. 2013). Current prices are estimated at approximately 0.31 $/W.

2.2. Technological Advancements in Solar Panels

Solar panels are the cheapest and the most efficient they have ever been. Technology is moving forward. Researchers at the National Renewable Energy Laboratory (NREL) in 2021 were able to achieve 39,46% efficiency of the PV cell in the lab conditions, and in 2022 Fraunhofer Institute for Solar Energy Systems ISE in Germany reached the top efficiency of 47.6 % for a four-junction solar cell-based on a III-V multijunction cell architecture. Even though these numbers are high, commercial solar panels have an efficiency almost twice as low. The reasons for that are the photovoltaic cell efficiency and the panel configuration (size, configuration, cell layout). Despite the fact that the production capabilities of solar panels on site are considerably inferior, the overall productivity of these devices has increased exponentially over the past few decades. In 2010, the average efficiency of solar panels was between 15 and 17%, whereas today this figure has reached 22 to 23%. This means that with increased performance, the return on investment will be significantly higher, and therefore this trend made it appealing to invest in such technology.

The modules used for large-scale installations are slightly less efficient than lab modules. New promising developments however make the technology more accessible, flexible, and profitable. Perovskite solar cells for example have the asset of being produced with low-cost materials with a high efficiency of over 21%. Another key technology would be bifacial modules, allowing the capture of direct sunlight on the front side and reflections on surfaces on the rear side, despite being slightly more expensive.

Solar panels are not the only thing that is important when investing in a solar electrostation. The biggest disadvantage that solar panels have is their intermittency, meaning that electricity can only be produced when the sun is active (Hassan et al., 2023). To partly avoid this problem hybrid systems are used. In hybrid systems, solar panels are connected to energy storage systems that allow the accumulation of an excessive amount of electricity during peak production hours, and its usage during high consumption hours or at night. Hybrid systems make SES more reliable and allow faster adaptation when consumption fluctuations occur. However, energy storage systems are not cheap and require big investments. But on the positive side is that lithium-ion batteries have reached their historically lowest price in 2024, the average cost of lithium-ion batteries per 1 kWh is now $115 (BloombergNEF). Even though batteries are expensive they are beneficial for both private household owners and in on-grid scenarios, for off-grid households batteries give an opportunity to become fully energy-independent. As for the on-grid systems, storage systems ensure stability with the power supply and allow to compensate for the errors in forecasts, since weather forecasts are not yet 100% predictable.

2.3. Adoption of SES and storage systems compared to other countries

Germany is one of the world leaders in solar panels installation. Despite not being among the European countries with the highest solar irradiance, the country managed to place itself as a leader by implementing strong support and focus, both in terms of technical aspects and regulations.

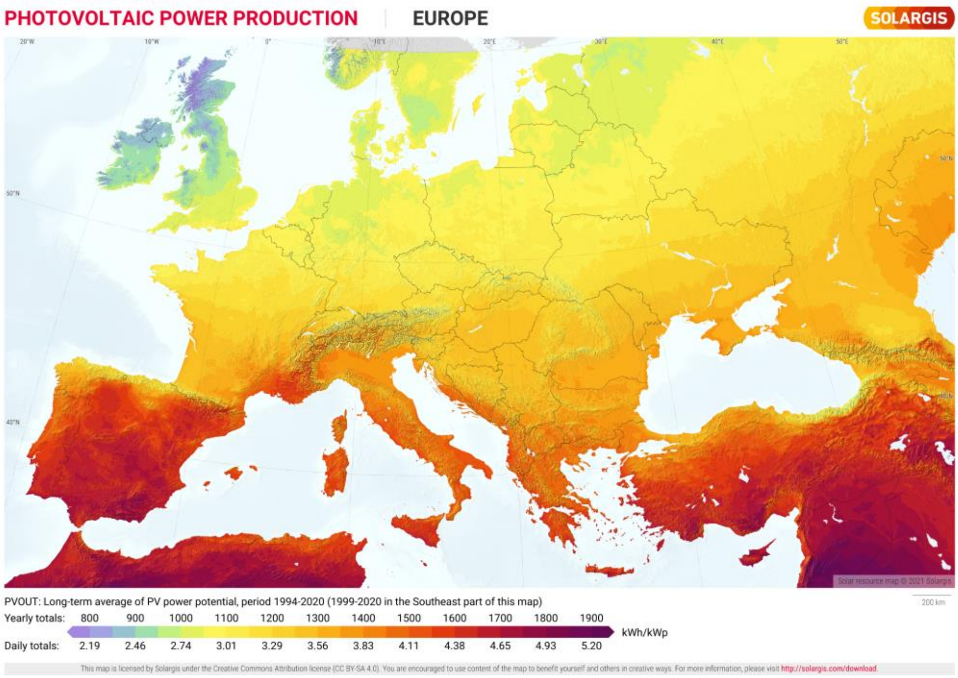


Figure C. Photovoltaic production potential

Source: Solar resource map © 2021 Solargis

This map provides an overview of photovoltaic power production potential. Despite not being geographically the most exposed, Germany is still the leader in the European Union, followed by Spain. The country is renowned for the high quality of its solar panel production and research and development. They are said to reach the highest efficiency worldwide. The main reasons for Germany's success in solar energy include for example:

- strong support from regulations and policies: Germany has set ambitious ecological transition goals, and Feed-in Tariffs were introduced to ensure long-term security for solar energy investors.

- national support: Germany has made the focus and adoption of renewable energy a priority. In addition to that, the country decided to decommission its last nuclear plants in 2023.

- modern grid: Germany's power grid is highly evolved, able to integrate solar energy, and is equipped with storage solutions.

According to Clean Energy Wire (CLEW) "Around seven gigawatt hours of new storage capacity will be added by 2026" (Large-scale battery storage in Germany set to increase five-fold within 2 years, Report, Oct 2024).

Storage batteries have shown to be a strategic asset for making the global adoption of solar panels easier. Spain raised this concern as well, implementing it as a top priority in their National Emergency Communications Plan: *"The rapid development of electric renewables makes it necessary to speed up the installation of storage"* (Integrated National Energy and Climate Plan, Update 2023-2030, Spanish Government, Ministry for the Green Transition and the Demographic Challenge). Spain planned to develop storage capacities and set a target of 22,5GW by 2030.

This storage is a direct answer to the instability of solar energy production during certain times of the day. It is a key for constant supply and therefore, optimization.

Compared to those examples, we can see that Ukraine follows a similar trend in terms of adoption and regulation. Indeed, a lot of new projects are launched towards state supported programs or the "Rebuild Ukraine" program. The energy sector is trying to raise investments for a large number of projects such as a 6.5MW solar power plant for the municipal enterprise of the Sumy City Council "Electroavtotrans", the construction of a 5MW Solar Power Station (Mezyrytska TC), Construction of solar power plants in Mygiivska hromada, construction of a 5MW Solar Plant from the Dobroslav settlement council, etc. Those projects don't target only solar energy, but all types of renewable energies, across the entirety of the country, with different sources of fundings (public or private). The complete list of projects can be found on the GB4U Website (Global Investment For Ukraine).

The government of Ukraine supports green energy initiatives and offers green tariffs for example as well, to make the investment in this industry more reliable and attractive, following the model of Europe, especially Germany as mentioned, that proved to work.

2.4. Long-term Impacts on Ukraine's Energy Independence and Sustainability

The problem of energy dependence has already been raised since the initial invasion of russia in 2014 (Kharlamova et al., 2016). Already at the time it was clear that high imports of fuels may lead to higher risks to national and social security. Based on the events of the last decade in Ukraine it becomes clear that the need for fully autonomous energy production is high. One of the ways to decrease the usage of combustibles and imported energy is to use resources that are easy to find in

Ukraine. The most excessive resource there is sun energy. Adoption of solar energy systems in Ukraine can lead to big long-term benefits including energy security, economic growth, and environmental sustainability. These aspects would help to build a more resilient, independent, and sustainable future for the country.

As was explored in sections 1 and 2 of this work there are many advantages of solar stations in comparison to the existing energy production in Ukraine.

Energy security. The first and most important one is the lack of necessity for the recurring supply of fuel. Not only does it make them low on operating costs, but also it could contribute to a stronger geopolitical position, diminishing external influences that leverage energy as a tool of power (Hassan et al., 2023).

In addition to external political threats, solar systems allow for diversification of the risks that occur because of natural disasters, system breakdowns, or geopolitical conflicts. The decentralized nature of solar systems lowers the vulnerability to disruptions which helps to create a reliable source of energy, even if difficulties in some regions occur.

Economic development. Some may argue that the initial investment in solar stations is too high, particularly those equipped with energy-storing systems. However, even though the initial cost is high, the operation cost does not require big funds. This type of RES does not need a constant fuel supply, a team of specialists on sight, or everyday maintenance. Therefore, it is very easy to count the return on investment from the amount of capital invested. As soon as the breakeven point is reached the cost of the electricity produced becomes very minimal. This means that in the long-term perspective, it will lower the cost of energy, benefiting households and industries, and boosting economic growth.

According to Lazard's Levelized Cost of Energy (LCOE) solar photovoltaic (PV) technology has undergone the most significant price decrease of 83% in recent years. LCOE also nicely illustrates that older technologies of electricity production are losing their efficiency and renewable energy sources show much more potential economically.

The growth of the solar energy sector may also positively influence the employment situation in rural areas since free lands are usually located outside of densely populated areas. This way underdeveloped regions will receive more employment opportunities based on maintenance and installation needs.

Ukraine is a very appealing country for investment in RES, because of fairly cheap lands, good energy prices, and satisfactory weather conditions. The only problem is the risks associated with the full-scale war. If the right instruments and policies were implemented that would help to mitigate those risks and attract even more foreign funds to develop an independent and resilient energy market.

Environmental sustainability. At the moment, more than half of the energy production capacities are destroyed. So, there is an urgent need to make a decision to rebuild the old system or invest in more green, resilient, and modern ways of energy production. Right now, there is a great opportunity to create capacities that align with the international environmental commitments. Solar stations produce no emissions during operation compared to coal, gas, and fuel, therefore developing a solar station network will reduce Ukraine's carbon footprint. Moreover, it will create a great image for Ukraine and support its commitments under international agreements like the Paris Agreement, contributing to global efforts to combat climate change. Proper planning and installation of SES could also contribute to the effective usage of unused or degraded land.

As a result, the integration of SES into the energy mix of Ukraine will provide positive long-term benefits to the country's geopolitical security, economic stability, and environmental sustainability. It reduces dependence on imported fuels, fosters economic development through energy cost reduction and job creation, and contributes to global environmental sustainability goals by significantly reducing carbon emissions. So, solar station adoption will help to mitigate the risks that the current energy system is facing, and also position Ukraine to become a more resilient, forward-thinking nation aligned with global progress. This progress is even more important since Ukraine agreed to the Paris Climate Accords. Ukraine aims "to reduce its greenhouse gas emissions by 65 percent by 2030 from the 1990 levels." (UNFCCC, 2021)

2.5. Challenges of SES installations

Since 2022, 14% of the industrial solar power plants in Ukraine have been damaged (ASEU, 2024). Considering the geopolitical situation of Ukraine, this is a very high threat for new and existing projects, especially since the most exposed zones are in or near occupied territories.

Another challenge in the installation of SES is the geographical choice. Indeed, it requires some large lands, leading to competition for the land use with the agriculture industry, for example, that represents Ukraine´s largest export industry. In addition, comes the fact that installations can´t be placed too far away from the grid, resulting otherwise in power losses during the transmission.

A solar farm can be demanding in terms of maintenance and care taking. To avoid the reduction of efficiency caused by dust or dirt for example, regular operations of cleaning are needed, as well as the maintenance. A continuous supervision is therefore mandatory, with the ability to react to any eventual issue mentioned or weather damages for example. The accurate management of all the material and human resources is in this case a precious key for ensuring the good functioning and return on investment.

Another important factor that is holding back the development of solar energy in Ukraine is existing regulatory environment. While the feed-in tariff is supposed to attract investment into the sector, the challenges remain. There is a lot of uncertainty when it comes to the situation in Ukraine, since the investors are in no way protected by the government. And installation process is complicated, because of the extensive bureaucracy.

To obtain a permit for the construction of solar power plants, it is necessary to collect the package of documents in accordance with Article 29 and Article 31 of the Law of Ukraine “On Regulation of Urban Development” (Закону України «Про регулювання містобудівної діяльності»). It is a general law that is applied to all construction projects, residential and non-residential. SES is the type of facility that does not need advanced structures or necessity to accommodate large numbers of people, therefore most of the points in the needed documentation based on the Articles are not applicable to such installations. The excessive amount of useless information that investors must collect makes the acquisition of such permits very time and energy-consuming, which may lead to delays in project installations or even abandonment of the project even at the initial stages.

Moreover, there is no targeted government planning or regulation to identify regions where additional solar stations are most needed. Right now, regulatory institutions cannot deny a request for permits for solar station construction if all the documents are in order. The responsibility for granting such permits primarily falls to local authorities. Unfortunately, the complicated application process as well as lack of centralized control of new SES installation can also lead to corruption, where investors are trying to bypass the application for the permit altogether.

Therefore, based on this information, the regulatory environment for alternative energy installations should be streamlined and modernized to ensure compliance with the needs of the market and ensure stability and growth of the solar energy sector.

CHAPTER 3. IN-DEPTH ANALYSIS OF THE ADDED VALUE FROM SUCH INSTALLATIONS (BASED ON CASES OF INSTALLED SES)

3.1. Financial Evaluation of SES Projects (Case studies)

The integration of an expanded solar energy infrastructure into Ukraine's energy portfolio would be beneficial not only in environmental terms but also with regard to socio-economic development. In this section of the work, there will be a price comparison of the total installation cost of solar panels in Ukraine 5 years ago and nowadays, as well as best practices of solar panel installation around the world, and predictions and recommendations regarding SES installations in Ukraine.

In order to facilitate an informed discussion on the financial implications of solar panel installation in Ukraine, the data derived from a previously undertaken project Oleksandrivka SES, situated within the Kherson region, will be used. The preparations for this project started at the beginning of 2019. The reasons for this project were at the time much lower prices than before for PV systems as well as the governmental incentive “green tariff”, which allowed the sale of green energy higher than the market prices. The goal was to put this station into operation in 2019 because the “green tariff” was expected to be lower in 2020. Another important aspect was to finish all of the work before the end of the peak insolation, so until the end of the summer, to be able to produce more energy to sell.

As in any other project, the first step was to calculate the costs and return on investments, to understand if the project is viable. To estimate the total energy produced in a year the following formula was used:

$$E = (I_{front} * \eta_{front} + I_{rear} * \eta_{rear}) * A_{module} * PR * t,$$

where

I_{front} - Irradiance on the front side of the panel (W/m²).

I_{rear} - Irradiance on the rear side of the panel (W/m²), dependent on ground reflectivity (albedo) and tilt angle.

η_{front} - Efficiency of the front side of the panel (typically the panel's rated efficiency).

η_{rear} - Efficiency of the rear side of the panel (a fraction of typically around 70-95% depending on the design).

A_{module} - Total active area of the solar panel (m²).

PR - Performance Ratio, which accounts for system losses (like temperature, shading, and wiring inefficiencies), typically between 0.75 and 0.90.

t - Time the panel is exposed to the given irradiance (days).

Below you will find a table with specifications regarding PV modules and Inverters.

Table 1

PV Array Characteristics		
PV module		Jolywood JW-D60N-310W Si-mono
Total number of PV modules		38745
Unit Nom. Power		310 Wp
Array global power	Nominal (STC)	12011 kWp
	At operating cond.	11019 kWp (50°C)
Total module area		63725 m²
Module efficiency		18,67%
Bifaciality		80%

Inverter	Huawei Technologies SUN2000-105KTL-H1
Nb. of inverters	88 units
Unit Nom. Power	105 kW
Max. power (=>25°C)	116 kW
Pnom ratio	1.30
Total Power	9240 kW

Based on the location, characteristics of modules, and inverters it was calculated that such a solar station would produce 17GWt per year. Considering that at the time of the green tariff, the price on the kWt was 0,15 euro/kWth. With rough calculations taken into account errors in forecasts, the inflation rate, and operational costs, the CAPEX would be returned in around 3,5 years. Overall CAPEX was around $7mio. (Please find all of the calculations in Annex 1 and 2). ROI 30% (at the same time on the market the average cost per kWh was 0,07 euro/kWth)

The case above shows that already in 2019 SES projects were very appealing because of their high return on investment as well as low operational costs. However, the biggest disadvantage of the Oleksandrivka project was the lack of storage system units. Such stations would not be able to fully cover the needs of the households since there is no energy generation during night hours. In 2019 when there was a wide variety of energy sources in Ukraine this probably was not a big problem, but in 2024 when a third of Ukraine’s electricity generation capacities were destroyed there is an urgent need for the replacement of deficient capacities that would be reliable, resilient, and efficient.

Current research emphasizes the significance and development of Hybrid Renewable Energy Systems (HRES). The role of storage systems, especially batteries, is crucial for the mitigation of the irregular nature of renewable sources and the facilitation of energy balancing, load leveling, and grid stability (Hassan et al., 2023). In order to draw parallels between the capital expenditure (CAPEX) and productivity of photovoltaic (PV) systems integrated with energy storage solutions, it is proposed to examine an additional case study of the SES from the Kyiv region in Tetiiv.

Table 2

PV Array Characteristics		
PV module		PNG Solar PNG144M-550 HALF-CELL MBB MONO PERC
Total number of PV modules		2069
Unit Nom. Power		550 Wp
Array global power	Nominal (STC)	1138 kWp
	At operating cond.	850 kWp
Total module area		5 359 m²
Module efficiency		21.28 %
Bifaciality		80%
Inverter		Huawei Technologies SUN2000-105KTL-H1
Nb. of inverters		10 units
Unit Nom. Power		105 kW
Max. power (=>25°C)		116 kW
Pnom ratio		1.30
Total Power		1050 kW
Batteries		4 mWh

Upon conducting a comparative analysis of the price per watt, disregarding the cost of batteries, the following observations were made: there has been a 27% decrease in price, from $0.74/W to $0.54/W. At the same time, there was an increase in energy prices, which served to further enhance the appeal of green energy sources.

The financial implications of capital expenditure (CAPEX) are significantly impacted by the inclusion of batteries, resulting in a less favorable return on investment (ROI). Nevertheless, it would be unreasonable to disregard the advantages that such technology offers. According to the new Ukrainian regulations, each renewable energy power plant must contain energy storage units with 4 mWh of batteries per 1 mW of plant capacity. Based on these specifications the price for the watt of energy will be 1,35$/W, which is 2,5 times higher than without. But as mentioned before, with the benefits that batteries bring, such costs are reasonable. They give an opportunity to:

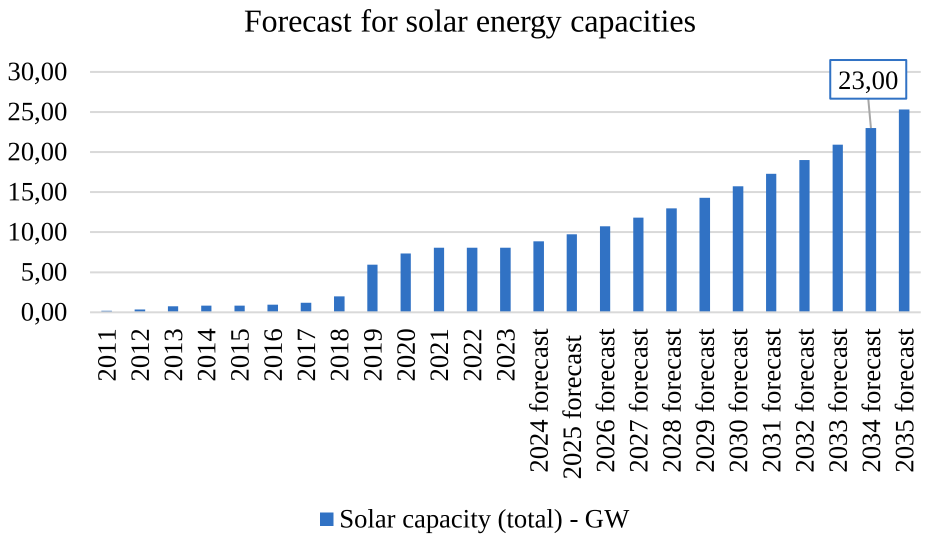
- supply electricity at night

- to store electricity at times of maximum production to balance supply during peak demand
- to respond quickly to an increase in demand during peak hours
- sell electricity at better prices during peak hours

3.2. Outlook for Hybrid Renewable Energy Systems (HRES)

Since the beginning of the full-scale invasion, russia targeted all of the possible objects of energy infrastructure. Some of the stations are now located in occupied regions (the biggest occupied object is the Zaporizhska nuclear station which had a capacity of 6 GW). Others are fully destroyed. Overall losses in capacity are estimated to be around 22 GW. According to KSE the estimated losses in the direct physical destruction of the energy sector in Ukraine is $16 billion. But since there are much more efficient and cheaper technologies on the market it would be wise not to restore some of the capacities, but to build more up-to-date solutions. The development of the decentralized renewable energy systems is supported as well by Ursula von der Leyen, the President of the European Commission, in her recent statement during her visit to Kyiv, Ukraine in September 2024.

Based on the data of Energy Institute there were no new capacities built in 2022 and 2023. Such stagnation after rapid growth of solar panels installations can be caused by the uncertainty that investors feel because of the ongoing war. The fear of not getting back the investment is higher than the possible profits from such installations. But from the research above it is clear that the risk should be taken because SES have opportunity to bring a lot of benefits to Ukraine during war time as well as in a post-war period. After the big spike in 2019, the growth rate for PV installations has settled a bit. In 2021 there has been a 10% increase in PV modules installation. Based on this number the forecast below was established. If a 10% yearly increase in SES capacities would be achieved, it would be possible to cover the lost energy capacities by 2034. Ideally that would be a solution that would help Ukraine gain more independence and resilience, but in times of war it is complicated to do forecasts, since there is no stable economy and stable environment for investment.



Graph 5. Forecast for solar energy capacities

Source of data: Energy Institute - Statistical Review of World Energy (2024)

Based on the calculations of the costs of SES + batteries installation the estimated cost for substituting destroyed capacities would be 22 GW * (1,35$/W * 1 000 000 000) = $ 29,7 billion. But during wartime, it looks unrealistic to attract such investments. More rational right now would be to substitute the urgent needs capacities to allow for the stable uninterrupted supply of electricity to households and businesses. In her statement, the President of the European Commission mentioned that 2,5 GW of capacity is roughly around 15% of Ukraine's needs. From these numbers, the total needed capacity is around 16,7GW of production possibilities. 16,7 GW * (1,35$/W * 1 000 000 000) = $ 22,5 billion.

CHAPTER 4. RESULTS OF THE FINDINGS AND RECOMMENDATIONS

This chapter presents the key findings of this research, which reflect the current state of the energy system in Ukraine, opportunities that recent technological findings in photovoltaic systems present, the socio-economic impact of SES adoption, and recommendations for short-term and long-term development of this sector.

The ongoing conflict has caused significant damage to Ukraine's energy production facilities, resulting in a reduction in capacity levels that are now three times lower than those recorded in 2021. This caused repeating blackouts, especially during peak morning and evening hours. Such problems that occurred led to the urgent need for decentralized and efficient solutions which would help to rebuild production capacities and would contribute to the resilience of the energy system. Before war times Ukraine already had a good share of RES in the energy mix reaching up to 12% of the total production. It was caused by a reduction in the price of solar modules as well as the introduction of the government incentive "green tariff".

Based on the data from the case studies of the Oleksandrivka SES and Tetiiv SES it was revealed that CAPEX for solar installations decreased by 27% over the past five years, from 0,74 $/W to 0,54 $/W. However, modern installations are usually built with storage systems that allow them to accumulate energy during peak production hours during the day and use them in the evening or at night when insolation is weak or absent. Storage systems in the form of batteries usually increase CAPEX significantly, in the case of Tetiiv SES by 2,5 times, raising the cost to 1,35 $/W. Despite the high cost, Hybrid renewable energy systems (HRES) like the mix of PV and Batteries provide significant benefits to such sort of facilities expanding their coverage of electricity needs throughout the day and the ability to sell energy at higher prices during peak energy demand. Additionally, based on Lazard's levelized cost of electricity (LCOE), renewable energy sources, like PV plants, are shown to be the cheapest, because of their low maintenance and operational expenses. That means that the long-term benefits of RES are much more appealing than the ones of traditional energy sources.

With the ongoing research, PV systems are expected to be even more efficient and even more cheap. Already now with the bifacial and perovskite cells solar stations show great efficiency that allows them to produce energy even in much less insolated regions.

There are a couple of successful cases of green energy development, like Germany or Spain. These countries show how supportive policies like feed-in tariffs help to boost this sector. Germany's Energy Transition Initiative emphasizes the importance of a clear regulatory framework and financial incentives, which can serve as a model for Ukraine.

Already since 2014, Ukraine has faced the problem of energy dependence. Back in the day, the actions towards creating self-sufficient energy should have been taken. Therefore, now is also no time to wait. SES gives an opportunity to enhance Ukraine’s energy security by lowering the dependency on imported fossil fuels and minimizing the risks of centralized infrastructure attacks.

In addition to having benefits for energy security renewables have great benefits for economic and environmental sectors. Low costs for operation and no requirements for outsourced products that are sometimes unpredictable in price allow to spend money in the energy sector more efficiently. And having low carbon emissions by nature SES provides Ukraine with the unique opportunity not only to restore the country but to fulfil international climate goals.

Alternative energy generation sources have plenty of benefits that a modern energy system should have. However, there are barriers that do not allow the widespread adoption of solar in Ukraine. The biggest ones are outdated and partially distracted grids, which do not allow for the connecting of high volumes of energy, high costs of such installations, and the risks related to the ongoing war in Ukraine.

Based on the findings the following recommendations to increase the adoption of SES are proposed.

- Restauration and modernization of the grid, to ensure the seamless connection of stations to the centralized energy system.

- Adoption and development of clear policies and regulatory support to create favorable conditions for those who are exploring the possibility of investing. This includes simplifying the permitting process, ensuring grid connection rights for SES developers, and providing tax incentives or subsidies to lower the financial barrier for entry. As it was mentioned in the previous chapters, requirements for SES constructions are still based on the general regulations for urban development. The requirements that are needed for solar stations are much less complex than for residential buildings. To ensure a faster application and approval it would be beneficial to establish the norms that are specifically tailored and adequate to SES installations as a separate construction unit. Because the current requirements are simply too high.

- Development of the platform that would provide current information on regulatory environment as well as be a place where all of the required paperwork could be obtained, simplifying communication between investors and governmental agencies.

- Attracting foreign investment through constant communication of the benefits that such projects can offer in Ukraine, such as high return on investment and high feed-in tariffs.

To successfully integrate SES within transitioning energy market a strategic approach should be used:

- Promotion of decentralized energy solutions, such as rooftop solar installations and microgrids, to reduce reliance on centralized power plants. Decentralization enhances energy security and provides resilience against potential disruptions.

- Collaboration with foreign renewable energy organization should be fostered to adopt global best practices of SES installations.

- Clear guidelines and protocols should be formed to ensure seamless connection to the grid.

- Locations with the limited connection to the traditional energy sources should be targeted first for SES projects. Because of the high efficiency of PV systems good electricity production values could be achieved even on moderately insolated places (like Tetiiv in Kyiv region).

- Education campaigns should be held to stimulate the transition and increase acceptance of difficulties that might come with the energy transition.

- Since SES is not the only renewable energy source, combination of wind and hydro would help increase share of energy production from renewables, as well as lower the risks caused by intermittency of such energy sources.

The recommendations above describe mostly the short-term options for boost of solar energy sector development. Right now, Ukraine is lacking big productions capacities that require immediate restauration. However, as it was presented in the example of Germany, uncontrollable capacities installation may also lead to problems like overproduction and grid instability. For this reason, a more centralized approach should be taken to ensure long-term coherent and predictable energy sector structure. The government should provide the regulatory function for the market of the alternative energy, establish a national SES roadmap, with clear targets for capacity growth, regulatory milestones, and technological advancements by 2035. As separate units SES could provide the benefits that they have but ensuring that all the energy production stations are working harmoniously is even better. As a regulatory institution the government should provide the renewed grid and a permit for a particular SES installation that should be sold on the auction. Such approach is also going to be implemented by Germany as it allows to control the amount of the capacities built. Since solar stations are extremely attractive right now because of their cheap price, it is expected that there will be competitors' rivalry to obtain such permissions on the auction.

The money acquired from the auctions could be used for subsidizing energy storage markets, that do require much more investment for now, but that allow to cover for intermittency of renewable energy sources. To ensure continuous energy supply from green energy short-term and long-term storage solutions should be found. For short-term solutions, to cover for fluctuations during the day, batteries have shown to work perfectly. But for long-term solutions, like summer to winter, pumped hydro storages, synthetic fuels, or hydrogen storage technologies should be used to be able to balance out the lower insolation in the winter season. With the growing popularity of solar and wind energy long-term green energy storage solutions are essential for implementation in the energy market. Pilot projects with the help of the government could be launched to ensure seamless integration storage units into the mix.

Storage of the energy and balancing of the energy supply is going to be a new market that does not yet exist in Ukraine. On the regulatory level there are no licences that would allow companies to store and re-sell the energy. Therefore, for the future such licence should be developed to create safe and understandable regulatory environment for such businesses.

To sum up, the findings of this study demonstrate that solar energy systems represent a viable and sustainable solution to Ukraine's current energy challenges. With a good plan SES could be a fast and efficient solution to mitigate the risk of energy shortages, impact on the economy, and environmental goals of Ukraine. PV and Battery technologies have shown to be a great solution when implemented into the energy mix of the country and therefore are worth the investment of time and finances.

CONCLUSIONS

This research has explored the strategic management of solar energy systems in Ukraine, underlining their potential to answer the country's current and future challenges, taking into consideration the conflict, sustainability, and independence.

Ukraine's energy infrastructure has been severely damaged during the war, reducing its production from 25GW to 9GW. This has been emergently showing the need for alternative and decentralized energy solutions.

Solar Energy Systems (SES), especially Hybrid Renewable Energy Systems (HRES), have proven to be feasible, considering the current geopolitical situation and sustainability engagements that Ukraine agreed to. Adapting to the international agreements and promises made by Ukraine, as well as moving closer to European standards is a high-value vision for the country and its relationship with Western neighbours. The long-term effect of a wider adoption would result in several assets such as job creation, overall energy cost reduction, and decentralization of production, allowing a better distribution overall in the country. The results of this research show that the investment in SES and integration of modern storage technologies would result in a higher independence to importation and non-sustainable fuels.

The case studies of Oleksandrivka and Tetiiv SES demonstrate the feasibility of SES projects in Ukraine. Despite high initial costs, declining CAPEX, low operational expenses, and advancements in energy storage make SES financially attractive. Furthermore, it aligns with Ukraine's commitment to climate goals of reducing the carbon footprint.

To ensure successful solar energy development and other renewable energy clear national strategy should be implemented:

1. Modernized regulatory environment: requirements that are tailored to solar station as a separate unit to reduce bureaucracy.
2. Project of expected production capacities: to avoid chaotic station installations and ensure coherent collaboration between energy units.
3. Strategic Partnerships: collaboration with international renewable energy organizations to adopt best practices and secure funding for SES projects.
4. Energy Storage and Balancing: invest in both short-term and long-term storage solutions to stabilize renewable energy supply and create energy balancing market.

Despite all the challenges faced during wartime and the lack of resource, the adoption of SES is an opportunity to rebuild the Ukrainian energy sector. Strategic policies and investments will make Ukraine more energy independent and position it as a frontrunner in green energy adoption.

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APPENDIX A

Preliminary assessment of the photovoltaic electricity production

Project	Tetiiv
Geographical coordinates	49.372480°, 29.675357° (49°22'21", 029°40'31")
Generated by	Global Solar Atlas
Map link	https://globalsolaratlas.info/map?s=49.37248,29.675357,10

PNG144M-550		
Power of 1 pannel	550	wh
Quantity of pannels	2 069	pcs
Overall power	1 137 950	wh
Sqm2 of 1 pannel	2,59	m^2
Sqm2 of all pannels	5359	m^2
Efficiency of pannels	21,28%	
Bificial efficiency	17,02%	
Price for 1 pannel	69,60 USD	
Overall price	144 000,00 USD	

Invertor SUN2000-105KTL-H1		
Nominal power	105	kWac
Total power	1050	kWac
Quantity	10	pcs
Efficiency of invertor	98,5%	
Price per invertor	6 000,00 USD	
Overall price	60 000,00 USD	

Batteries		
Storage system (Accumulator)	4	MW/h
Price per MW/h	200 000,00 USD	
Overall price	800 000,00 USD	

Direct normal irradiation [Wh/m²]												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	4	23	9	-	-	-	-	-
5 - 6	-	-	-	16	128	170	120	48	-	-	-	-
6 - 7	-	-	23	153	270	284	243	227	105	8	-	-
7 - 8	-	20	176	258	358	372	333	336	261	153	10	-
8 - 9	75	152	270	338	428	441	418	416	340	261	101	53
9 - 10	169	217	328	402	471	481	460	480	403	311	148	131
10 - 11	197	244	358	422	480	483	472	498	418	341	171	146
11 - 12	191	241	354	408	461	459	455	480	397	343	165	138
12 - 13	183	232	345	383	423	433	418	460	379	327	168	134
13 - 14	182	230	331	359	395	407	393	442	366	317	170	129
14 - 15	165	240	317	334	367	378	370	410	340	293	153	111
15 - 16	79	192	275	295	333	345	336	372	301	229	68	29
16 - 17	-	90	215	261	309	319	312	332	240	40	-	-
17 - 18	-	-	40	194	268	289	279	265	80	-	-	-
18 - 19	-	-	-	27	134	222	187	59	-	-	-	-
19 - 20	-	-	-	-	1	45	19	-	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
SUM	1 241	1 858	3 032	3 850	4 830	5 151	4 824	4 825	3 630	2 623	1 154	871
Multiplyed by the number of days in a month	38 471	52 024	93 992	115 500	149 730	154 530	149 544	149 575	108 900	81 313	34 620	27 001

SUM in a year	
1 155 200	Wh/m^2

Energy production KWh/h

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	5	28	11	-	-	-	-	-
5 - 6	-	-	-	19	154	204	144	58	-	-	-	-
6 - 7	-	-	28	184	325	341	292	273	126	10	-	-
7 - 8	-	24	212	310	430	447	400	404	314	184	12	-
8 - 9	90	183	325	406	514	530	502	500	409	314	121	64
9 - 10	203	261	394	483	566	578	553	577	484	374	178	157
10 - 11	237	293	430	507	577	581	567	599	502	410	206	175
11 - 12	230	290	425	490	554	552	547	577	477	412	198	166
12 - 13	220	279	415	460	508	520	502	553	456	393	202	161
13 - 14	219	276	398	432	475	489	472	531	440	381	204	155
14 - 15	198	288	381	401	441	454	445	493	409	352	184	133
15 - 16	95	231	331	355	400	415	404	447	362	275	82	35
16 - 17	-	108	258	314	371	383	375	399	288	48	-	-
17 - 18	-	-	48	233	322	347	335	319	96	-	-	-
18 - 19	-	-	-	32	161	267	225	71	-	-	-	-
19 - 20	-	-	-	-	1	54	23	-	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
SUM	1 492	2 233	3 644	4 628	5 806	6 191	5 798	5 800	4 363	3 153	1 387	1 047
Multiplyed by the number of days in a month	46	63	113	139	180	186	180	180	131	98	42	32

SUM in a year	
1 389	Mwh
0,26	Mwh/m^2

Sales from PV energy production	Sales from batteries	Total profit in a year
208 278,49 USD	188 000,00 USD	396 278,49 USD

COSTS		
PV moules	144 000,00 USD	0,13 USD
Inverters	60 000,00 USD	0,06 USD
Installation costs (installation, metal structures, grid)	132 000,00 USD	0,12 USD
General construction works (fences, roads)	100 000,00 USD	0,09 USD
Soft costs	170 000,00 USD	0,15 USD
SUM	606 000,00 USD	
Baterries 4MWh	800 000,00 USD	0,80 USD
SUM with baterries	1 406 000,00 USD	
Price per Watt PV		0,54 USD
Price per Watt PV + Batteries		1,34 USD
ROI PV		26%
ROI PV + Batteries		23%

APPENDIX B

Preliminary assessment of the photovoltaic electricity production

Project	Oleksandrivka
Geographical coo	46.613962°, 32.111895° (46°36'50", 032°06'43")
Generated by	Global Solar Atlas
Map link	https://globalsolaratlas.info/map?s=46.613962,32.111895,10&pv=ground,180,35,1000

Jolywood JW-D60N-310W Si-		
Power of 1 pannel	310	Wh
Quantity of pannels	38 745	pcs
Overall power	12 010 950	Wh
Sqm2 of 1 pannel	1,64	m^2
Sqm2 of all pannels	63 725	m^2
Efficiency of pannel	18,67%	
Bificial efficiency	14,94%	
Price for 1 pannel	70,00 USD	
Overall price	2 712 150,00 USD	

Invertor SUN2000-105KTL-H1		
Nominal power	105	kWac
Total power	9 240	kWac
Quantity	88	
Efficiency of inverto	98,5%	
Price per invertor	6 000,00 USD	
Overall price	528 000,00 USD	

Direct normal irradiation [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	0	0	0	0	0	0	0	0	0	0	0	0
1 - 2	0	0	0	0	0	0	0	0	0	0	0	0
2 - 3	0	0	0	0	0	0	0	0	0	0	0	0
3 - 4	0	0	0	0	0	0	0	0	0	0	0	0
4 - 5	0	0	0	0	10	28	10	0	0	0	0	0
5 - 6	0	0	0	14	136	181	144	56	13	0	0	0
6 - 7	0	0	50	156	280	296	300	262	190	29	0	0
7 - 8	6	62	190	275	374	393	418	392	340	224	56	0
8 - 9	114	198	281	360	453	480	521	492	434	335	172	112
9 - 10	185	258	351	426	512	531	581	570	498	400	225	192
10 - 11	216	296	381	460	540	548	602	606	523	434	247	222
11 - 12	213	302	383	468	538	551	595	604	516	435	247	214
12 - 13	212	296	375	460	514	517	563	576	502	425	247	203
13 - 14	205	292	364	445	495	482	523	536	474	405	230	188
14 - 15	181	280	335	413	458	451	480	484	423	363	201	160
15 - 16	86	220	274	366	409	405	431	423	360	262	86	55
16 - 17	0	88	208	293	350	355	379	354	264	51	0	0
17 - 18	0	0	39	179	266	288	314	256	56	0	0	0
18 - 19	0	0	0	16	105	170	181	47	0	0	0	0
19 - 20	0	0	0	0	0	12	10	0	0	0	0	0
20 - 21	0	0	0	0	0	0	0	0	0	0	0	0
21 - 22	0	0	0	0	0	0	0	0	0	0	0	0
22 - 23	0	0	0	0	0	0	0	0	0	0	0	0
23 - 24	0	0	0	0	0	0	0	0	0	0	0	0
Sum	1418	2292	3231	4331	5440	5688	6052	5658	4593	3363	1711	1346
Multiplyed by the number of days in a month	43958	64176	100161	129930	168640	170640	187612	175398	137790	104253	51330	41726

SUM in a year	
1 375 614	Wh/m^2

Energy production KWh/h												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	125	351	125	-	-	-	-	-
5 - 6	-	-	-	176	1 705	2 270	1 806	702	163	-	-	-
6 - 7	-	-	627	1 956	3 511	3 712	3 762	3 285	2 383	364	-	-
7 - 8	75	777	2 383	3 448	4 690	4 928	5 242	4 916	4 264	2 809	702	-
8 - 9	1 430	2 483	3 524	4 514	5 681	6 019	6 533	6 170	5 442	4 201	2 157	1 404
9 - 10	2 320	3 235	4 402	5 342	6 420	6 659	7 286	7 148	6 245	5 016	2 821	2 408
10 - 11	2 709	3 712	4 778	5 768	6 772	6 872	7 549	7 599	6 558	5 442	3 097	2 784
11 - 12	2 671	3 787	4 803	5 869	6 746	6 909	7 461	7 574	6 471	5 455	3 097	2 684
12 - 13	2 658	3 712	4 702	5 768	6 446	6 483	7 060	7 223	6 295	5 329	3 097	2 546
13 - 14	2 571	3 662	4 565	5 580	6 207	6 044	6 558	6 721	5 944	5 079	2 884	2 358
14 - 15	2 270	3 511	4 201	5 179	5 743	5 656	6 019	6 069	5 304	4 552	2 521	2 006
15 - 16	1 078	2 759	3 436	4 590	5 129	5 079	5 405	5 304	4 514	3 285	1 078	690
16 - 17	-	1 104	2 608	3 674	4 389	4 452	4 753	4 439	3 311	640	-	-
17 - 18	-	-	489	2 245	3 336	3 611	3 938	3 210	702	-	-	-
18 - 19	-	-	-	201	1 317	2 132	2 270	589	-	-	-	-
19 - 20	-	-	-	-	-	150	125	-	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	17 782	28 741	40 516	54 310	68 217	71 327	75 892	70 951	57 596	42 172	21 456	16 879
Multiplyed by the number of days in a month	551	805	1 256	1 629	2 115	2 140	2 353	2 199	1 728	1 307	644	523

SUM in a year	
17 250	Mwh
0,27	Mwh/m^2

Sales from PV energy production	
With "green tariff"	2 587 513,47 USD
With market prices	1 121 255,84 USD

ROI with "green tariff"	28,5%
ROI with market prices	11,2%

COSTS	
PV moules	0,32 USD
Inverters	0,05 USD
Installation costs (installation, metal structures, grid)	0,12 USD
General construction works (fences, roads)	0,10 USD
Soft costs	0,15 USD
SUM	

Price per Watt PV	0,74 USD