HUNGARIAN UNIVERSITY OF
AGRICULTURE AND LIFE SCIENCES

INSTITUTE OF ENVIRONMENTAL SCIENCE

THESIS

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Master of Science in Environmental Engineering

Szent István Campus, Gödöllö
2023

Hungarian University of Agriculture and Life Science

Szent István Campus

Master Science in Environmental Engineering

THESIS TITLE

Feasibility of Renewable Energy on an Urban Scale in Hungary, Spatiotemporal Analysis and Forecasting by AI (ARIMA Model) and Policy Analysis

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Szent István Campus, Gödöllö
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INSTITUTE OF ENVIRONMENTAL SCIENCE

INSTITUTE OF ENVIRONMENTAL SCIENCE, ENVIRONMENTAL ENGINEERING
(MSC) Technical Development specialization

THESIS

worksheet for

Shahal Ibn Islam Joy (JRKVWY)

(MSc) student

Entitled:

Feasibility of Renewable Energy on an Urban Scale in Hungary, Spatiotemporal Analysisand Forecasting by AI (ARIMA Model) and Policy Analysis

Task description:

This study examines the incorporation of renewable energies in Hungary's urban locales, highlighting solar and geothermal as prime candidates amidst various renewables. It outlines three solar energy methods through simulations, design diagrams, and economic evaluations for projects like EV stationsand a Floating Solar Park. The research also forecasts the energy landscape up to 2041, scrutinizing renewable production, consumption, and Hungary's potential energy independence. Additionally, it assesses whether current policies can meet renewable targets given existing infrastructure.

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Submission deadline: 06 November 2023.

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As an independent consultant of the author of this thesis, I hereby declare that the student took partin the planned consultations.

Gödöllő, 06 November 2023.

Szabó Márta

(Consultant)

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Acknowledgement

All praise goes to Almighty Allah (SWT). In my life, there are two most important people: one is my mother, and the other is my wife. I feel that I am chasing my mother's dream, which is why I am here today. The second woman in my life is my wife, who holds my hand through every odd. I am really grateful to both of them. Additionally, I want to show gratitude to the Tempus Public Foundation for selecting me for this scholarship award. I would like to thank everyone who has given their time and effort to address my queries and assist me in completing this thesis paper. Last but not least, I want to say thank you to my supervisor, Dr. Szabo Marta, for her kind guidance and supervision.

Abstract

The urgency to transit urban energy systems to renewable source is a pivotal response to the growing need for environmental and energy security. Globally, the trend towards renewables is more pronounced in the cities within high GDP per capita nations, signifying a clear interrelation between economic wealth and the pursuit of sustainable energy objectives. Urban areas are uniquely positioned to adopt a multitude of renewable technologies such as solar, bio-energy, and waste-to-energy conversion. However, the feasibility of wind energy in the densely populated regions is often constrained by land scarcity, necessitating creative integrations within urban infrastructures.

Fossil fuels, while historically central to economic growth, now present enduring environmental and economic challenges, evidenced by their contribution to air pollution and climate change. The United Nations' Sustainable Development Goals provide a blueprint for increasing renewable energy use and efficiency by 2030, advocating for equitable and universal energy access. Recent energy crises, exacerbated by geopolitical tensions, have highlighted the vulnerability of the current energy system, prompting immediate mitigatory actions and strategic shifts towards more resilient and sustainable energy models.

Urban centers, responsible for a major share of global energy consumption and carbon emissions, are at the forefront of this shift. Their expansion and the projected increase in urban populations, particularly in developing countries, underscore the necessity for a robust transition to renewable energy to ensure future energy security and address the intertwined issues of climate change and urbanization. The global move-away from fossil fuels towards renewables like solar and wind is critical for achieving net zero carbon emissions and cultivating a sustainable energy landscape for future generations.

This research endeavors to identify the most suitable renewable energy sources for urban-scale deployment in Hungary. It aims to propose potential solutions and feasible designs for harnessing renewable energy within this context while assessing the economic viability of these designs. Furthermore, the study seeks to analyze the energy trends over the next twenty years, with a particular emphasis on the contributions from renewable energy sources. The final objective of this research is to examine the current energy policies to determine if the projected targets for renewable energy adoption are attainable with the existing infrastructure for renewable energy extraction in Hungary.

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Chapter 1: Introduction

1.1 Background and Context

The contemporary energy landscape can be categorized into three main groups: fossil fuels, renewable energy sources, and nuclear sources [1]. In response to mounting imperatives for environmental stewardship and energy security, there is a discernible urgency to transition toward alternative energy sources, particularly renewables, within urban agglomerations. This strategic pivot is underscored by the capacity of renewable resources to effectively curtail the prodigious emissions of carbon dioxide. While a substantial number of cities worldwide have embraced renewable energy aspirations, the preponderance of these efforts is concentrated within the United States of America and the Europe. Concurrently, Asia and Africa grapple with the intersecting challenges of burgeoning urban pollution and escalating energy requirements. A recent report disseminated by the International Renewable Energy Agency (IRENA) reveals that an overwhelming majority of the 671 surveyed cities possessing renewable energy ambitions are ensconced within high GDP per capita nations. Precisely, this cohort constitutes 82% of the cities in question. This correlation between renewable energy aspirations and economic prosperity offers salient insights into the entwined dynamics of economic indicators and sustainable energy paradigms.

In the pursuit of expeditious clean energy realization and the concomitant decarbonization of the energy sector, urban landscapes bear the capacity to accommodate an array of renewable and unconventional energy sources. These encompass, among others, solar energy, bio-energy, hydro-power, and waste-to-energy technologies while wind energy garners acclaim as a promising economical and ecologically friendly energy source, its widescale deployment encounters impediments correlated with land availability. Notably, the exigencies of land scarcity within urban and suburban environments render the establishment of expansive wind energy installations impracticable. An innovative avenue for exploration entails the amalgamation of wind energy systems into the architectural fabric of urban settings.

The contemporary metamorphosis in the global energy milieu is precipitated by a confluence of challenges stemming from fossil fuel dependence. Although fossil fuels have historically propelled industrialization and economic advancement, their protracted utilization has engendered intractable challenges, including pernicious air pollution and the release of greenhouse gases. The ensuing deleterious impact on climate systems is a clarion call for comprehensive decarbonization measures. The Sustainable Development Goals (SDGs) instituted by the United Nations delineate a structured framework to achieve a significant upsurge in the adoption of renewable energy resources and heightened energy efficiency by the culmination of 2030. This initiative encompasses an encompassing spectrum of objectives, encompassing not only the amplification of renewable energy adoption and energy efficiency enhancement but also the promotion of just and inclusive energy accessibility. The focal points of discourse within this context pertain to the domains of energy efficiency optimization and the equitable facilitation of energy access.[1]

The recent upheavals in the global energy spectrum, instigated by a confluence of factors including geopolitical events such as Russia's foray into Ukraine, have unmasked the fragility and lack of long-term viability inherent in prevailing energy infrastructures. The resulting crisis has precipitated substantial perturbations in key energy markets spanning natural gas, coal, electricity, and oil. This turmoil accentuates the susceptibility of energy markets to external disruptions. Governments on a global scale are orchestrating immediate palliative measures to ameliorate the immediate repercussions and simultaneously architecting strategic frameworks that expedite the transition toward energy architectures characterized by heightened resilience and ecological cognizance. These endeavors encompass policies calibrated to amplify the prominence of renewable energy sources, diversify oil and gas supply chains, and engender augmented energy efficiency. [2] The shift to renewable energy could destabilize geopolitical processes predicated on fossil fuel distribution. Many countries can gain energy independence by switching from resource scarcity to abundance through renewable energy. This transformation disrupts fossil fuel extraction and distribution power dynamics. [3]

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[1] *The politics of a changing global energy landscape. (2022, March 21). LSE International Development.* https://blogs.lse.ac.uk/internationaldevelopment/2022/03/21/the-politics-of-a-changing-global-energy-landscape accessed 12 October 2023.

[2] *World Energy Outlook 2022 shows the global energy crisis can be a historic turning point towards a cleaner and more secure future*. IEA. https://www.iea.org/news/world-energy-outlook-2022-shows-the-global-energy-crisis-can-be-a-historic-turning-point-towards-a-cleaner-and-more-secure-future accessed 12 October 2023.

[3] *How the Global Energy Transition is Set to Disrupt the Geopolitical Landscape. (2019, April 5).* Chatham House. https://www.chathamhouse.org/2019/04/how-global-energy-transition-set-disrupt-geopolitical-landscape accessed 14 October 2023.

China, in its capacity as the preeminent global energy consumer and greenhouse gas emitter, has embarked on a transformative trajectory to ameliorate energy consumption patterns and redress environmental ramifications. By pioneering investments in renewable energy, China has ascended to a vanguard position in the realm of wind and solar energy production while concurrently embracing widescale adoption of electric vehicles. Similar progress can be observed in other countries, such as the United States, Germany, Japan, the United Kingdom, India, and Brazil. The concerted drive towards renewable energy technologies, encapsulating the diminution of fossil fuel dependence, reflects a collective endeavor to expedite the transition toward energy matrices underpinned by sustainability and resilience.

In consonance with prognostications presented by the International Energy Agency (IEA), divestiture from fossil fuels emerges as a linchpin in the realization of overarching global climate objectives. This observation is discerned within the contours of the IEA's World Energy Outlook, wherein stringent climate-focused scenarios portend a plateau or decline in fossil fuel demand. Specifically, coal, natural gas, and oil are anticipated to undergo attenuation in consumption over ensuing decades. In tandem, the ascendancy of renewable energy sources, fortified by concurrent strides in energy efficiency, ensconces them at the vanguard of these trajectories, thereby fostering a more sustainable and secure energy tapestry.

The utilization of renewable energy sources holds remarkable significance in our progressively urbanized global society, as it is crucial to properly address the escalating energy demands and the accompanying environmental issues. The imperative to transition is heightened by the interconnected global energy crises and climate change. The issue of climate change is intricately linked to the global energy dilemma. Considering the significant environmental impact associated with coal, which is recognized as the most environmentally detrimental fossil fuel, and the escalating expenses related to natural gas, there exists an urgent imperative to explore and adopt greener energy alternatives [2].

The adverse effects of extensive fossil fuel consumption on climate change have been recognized by international organizations such as the United Nations (UN) and many governments. There exists a widely accepted agreement regarding the imperative of attaining substantial targets for the reduction of carbon emissions. The shift from conventional, i.e., fossil fuels, to sustainable energy sources like solar and wind holds significance in attaining the net zero carbon emission goal [3]. Urban regions have a substantial impact on the global consumption of energy resources Urban areas accounted for 64% of global primary energy use and 70% of carbon dioxide emissions in 2013. Based on the predicted expansion of urban populations and economic activity, it is expected that these statistics will persistently rise. [4] Over the course of the previous two decades, there has been a notable rise in the geographical scope of metropolitan areas. Currently, the population in urban areas is 3.5 billion in metropolitan areas, this phenomenon is notably seen in developing nations that are undergoing rapid transitions from rural to urban-based economies. The expected population growth of over 9 billion by 2050 will expand urbanization, especially in developing countries. Consequently, this will lead to a greater need for reliable energy resources. [5]

The importance of transitioning to renewable energy sources becomes increasingly crucial in urban contexts. Renewable energy is an intriguing technique to reduce carbon emissions, energy consumption, and urban sustainability. The paradigm under discussion includes solar, wind, hydro, and other similar renewable energy sources. It offers a noticeably cleaner and more sustainable alternative to traditional fossil fuel reliance. This alternative leads to a simultaneous decrease in carbon emissions and promotes a more environmentally conscious energy mix [4]. The compendium of multifarious challenges wrought by fossil fuel dependency, spanning ecological degradation, climatic perturbation, and geopolitical vicissitudes, has galvanized a collective global pivot toward cleaner, more sustainable, and secure energy modalities. Governments, industries, and societies writ large are progressively reckoning with the imperatives of diminishing dependence on fossil fuels and embracing renewable energy technologies as precursors to the engenderment of a sustainable energy future for posterity.

1.2 Research Problem and Significance

Urban centers are increasingly being acknowledged as crucial hubs that have a notable impact on shaping the future direction towards sustainable energy systems. In order to address the urgent issue of climate change and successfully achieve the stated goals of the Sustainable Development Goals (SDGs) set forth by the United Nations, it is crucial to

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[4] *Cities are at the frontline of the energy transition - News - IEA*. (n.d.). IEA. https://www.iea.org/news/cities-are-at-the-frontline-of-the-energy-transition accessed 16 October 2023.

[5] United Nations. (n.d.). *Sustainable urban energy is the future | United Nations*. https://www.un.org/en/chronicle/article/sustainable-urban-energy-future accessed 16 October 2023.

implement important reforms in the management of natural resources and energy consumption. This necessitates significant changes, characterized by a substantial decrease in the scale of greenhouse gas emissions and a substantial reconfiguration of economic structures to align with the principles of a circular economy [5]. The present phase of the research endeavor revolves around the viability of integrating renewable energy sources into metropolitan environments. Throughout history, there has been a prevalence of centralized energy models that have been rooted in national planning. These models have exerted significant influence over infrastructural investments within specific time periods [6]. Nevertheless, this method of modeling has come across notable challenges, such as the deterioration of the environment, the depletion of fossil fuels, and territorial disparities resulting from these models [6]. This necessitates a paradigm shift in the energy framework, placing a strong emphasis on the diversification of energy sources and a strategic shift towards the adoption of localized renewable energy options.

The importance of transitioning from non-renewable energy sources to sustainable alternatives has become increasingly significant in the present period. Throughout the past century, human civilization has heavily depended on hydrocarbon reserves, which include petroleum, coal, and natural gas. The hydrocarbon industry has played a significant role in the global energy sector, meeting more than 80% of the world's energy needs. However, it is important to note that this industry is also responsible for around 89% of the total greenhouse gas emissions globally [7]. Given the increasing intricacy resulting from climate change and environmental degradation, which have significant impacts on human welfare, there is a clear and urgent need for universally applicable sustainable solutions. The urgency of the situation is heightened by the inherent strategic weaknesses associated with dependence on imported fossil fuels, which particularly compromises energy security.

The increased sense of urgency aligns seamlessly with the broader patterns of global policy dynamics. The proactive involvement of the European Union (EU) in advancing the trajectory towards a low-carbon societal fabric and sustainable energy frameworks is particularly emblematic. The evident determination of these individuals is clearly demonstrated via their steadfast dedication to the Paris Agreement on climate change and their firm adoption of the 17 Sustainable Development Goals (SDGs) [5]. Significantly, in this particular framework, Sustainable Development Goals (SDGs) 7 and 11 emerge as particularly important, emphasizing the importance of accessible and sustainable energy and highlighting the crucial role of sustainable urban areas and communities. The Enhanced Advantages Associated with the Implementation of Renewable Energy in an Urban Setting.

Environmental Impact: Renewable energy sources play a significant role in mitigating environmental degradation, serving as a strong protective barrier. Given the evident tendency of the formation and utilization of fossil fuels to initiate the emission of greenhouse gases, the transition towards renewable energy sources becomes highly relevant in addressing the widespread effects of global warming and the resulting series of consequences related to climate change [7]**.**

Economic Viability: The economic viability of renewable energy technology has led to simultaneous reductions in financial costs and environmental impacts associated with energy production. The projected trends reveal a significant increase in the utilization of renewable energy, indicating a noticeable rise in its relative share within the global energy landscape. It is anticipated that the proportion of renewable energy will increase significantly, rising from 14% in 2018 to an estimated 74% by the year 2050 [7] Furthermore, the implementation of energy conservation efforts in metropolitan areas frequently exhibits noticeable economic viability, especially when supported by incentivized mechanisms provided by the public sector [5].

Diversification and Security: The integration of diverse renewable energy sources enhances the efficiency and balance of the energy grid. The integration of different energy sources in a cohesive fusion is a process that effectively counteracts the unpredictable nature inherent in each individual source. This results in a continuous and uninterrupted flow of energy. The combination of several energy sources, known as hybrid systems, offers several benefits including increased reliability, reduced energy storage needs, and improved operating efficiency [7].

Local Implementation: The adoption of renewable energy initiatives, such as the installation of photovoltaic solar arrays on public buildings, brings tangible benefits to the surrounding communities. In addition to enhancing energy security, these measures foster a positive cycle by facilitating the development of sustainable urban evolution. Instances such as the Soria case in Spain, which examined the practicality of renewable energy in meeting the energy needs of municipal buildings, serve as a model that urban areas can follow based on their specific circumstances [8].

Promotion of Smart Cities: The integration of renewable energy sources into urban environments plays a crucial role in enhancing the progress of intelligent urbanization. The trajectory discussed here manifests in the form of 'smart cities', which are defined by their strategic utilization of technology and data-driven frameworks to promote comprehensive human well-being. The congruence shown in this narrative aligns seamlessly with the pedagogies that support policies promoting sustainable urban development. It emphasizes a thematic focus on energy efficiency and the integration of renewable energy sources[8]

The orchestration necessary for incorporating renewable energy into urban areas extends beyond a simple technological challenge. It evolves into a crucial requirement, especially considering the existing environmental and socioeconomic urgencies. The imperative to adopt this paradigm is unequivocal, as it offers the potential to yield benefits that span both the realms of environmental sustainability and economic prosperity. This urgent need requires a steadfast dedication to rigorous academic research and collaborative efforts.

1.3 Research Question

The primary aim of this study is to explore the potential of renewable energy in Hungary, with a particular emphasis on urban areas. This research delves into past energy production and consumption trends to understand shifts over the years. Additionally, a critical analysis of policies regarding renewable energy extraction is undertaken to determine their viability. Throughout this inquiry, two main questions are addressed:

Question 1: Can Hungary, especially its urban regions, feasibly adopt renewable energy? And among renewable sources like Solar, Wind, Hydro, Biogas, Biomass, Biofuels, and Geothermal, which are the most suitable for the Hungarian context?

Question 2: How is the energy landscape projected to change in Hungary over the forthcoming two decades? And is it feasible for Hungary to meet its renewable energy targets as stated in its policy documents?

Chapter 2: Literature Review

2.1 Feasibility of Energy Mixing in Urban Area in Hungary

Every day, there is a growing increase in the use of electricity. Simultaneously, traditional energy sources such as coal and fossil fuels, including gasoline and diesel, are being exhausted at an alarming rate. Kandpal et al. addressing the escalating electricity demand requires the exploration of alternative methods for power generation [14]. Johansson et al explained green energy sources, such as solar and geothermal energy, are characterized by their minimal or often overlooked CO2 emissions, making them a pivotal solution in the quest for environmentally sustainable power generation. Unlike traditional fossil fuels, which contribute significantly to greenhouse gas emissions and global warming, these clean energy alternatives produce negligible pollutants. By prioritizing and investing in such eco-friendly sources, countries can significantly mitigate their carbon footprint and align with global climate goals, fostering a cleaner, more sustainable future for all [15]. Azofra et al. explained the significant expansion of solar photovoltaic (PV) power generation in recent years can be attributed primarily to environmental awareness, the urgent issue of global warming, decreasing PV module expenses, government support, and a widespread emphasis on renewable energy [16].

Renewable energy sources like PV systems are widely employed to generate electricity in response to the increasing need for power. PV systems are further classified into three distinct configurations: on-grid, off-grid, and hybrid solar energy systems. On-grid solar energy does not require external storage whereas off-grid solar energy systems come equipped with energy storage capabilities, enabling them to supply backup power to loads even when sunlight is unavailable. Alam et al. explained a hybrid solar system is a combination of an On-grid and Off-grid system [17]. According to data from the International Energy Agency (IEA), there was a 22% increase in worldwide solar PV production in 2021, totaling 1179 TWh from the previous year. The IEA highlighted that, among all renewable energy forms in 2021, solar power ranked second in terms of growth, with wind energy taking the lead.[6] Mellit et al. given the notable expansion in solar power production, solar PV facilities have become increasingly important in the energy sector [18]. Grid-tied solar power systems have

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[6] International Energy Agency (IEA). Solar PV. 2022. Available online: https://www.iea.org/reports/solar-pv accessed 20 October 2023.

a direct connection to the electrical grid. Romero et al. explained they feed power into the grid during daylight hours or when sunlight is present, helping to offset the energy needs of local demands [19].

The output of photovoltaic system generally depends on the geographical location of the solar photovoltaic panel. According to the *European Commission's Energy Report (2019)*, Hungary has made significant progress in its renewable energy sector, especially in solar energy. Zsiborács et al. (2023) developed a model for the realization of PV power plant projects in Hungary, emphasizing the country's innovative approach towards photovoltaic integration [20]. Zsiborács et al. (2019) conducted an economic analysis of grid-connected PV systems in Hungary, showcasing the evolving dynamics and potential profitability of such ventures [20]. Atsu et al. (2021) conducted a comprehensive assessment of the solar PV landscape in Hungary [21]. The research found that as of 2017, Hungary's installed grid-connected solar PV system capacity underwent considerable expansion, reflecting the nation's growing commitment to renewable energy and sustainable practices. Delving into the techno-economic aspects, Antal et al. (2019) [22] highlighted those external factors beyond just economic considerations that played a role in the slow adoption of wind and solar energy in Hungary.

The study relied on document analysis and expert interviews to conclude that non-economic factors, possibly political or regulatory, may have hampered the transition to renewable energies in the country. Lastly, a broader perspective on renewable energy emphasizes the urgency and importance of a future energy system that is resilient and adaptable, especially in the face of climate change impacts such as droughts, heatwaves, and storms. The European Environment Agency highlighted the criticality of these transitions, particularly for countries in Europe that are heavily reliant on traditional energy sources, indicating a pressing need for nations, including Hungary, to adapt to renewable energy paradigms for a sustainable future.[7]

The effectiveness of a photovoltaic (PV) setup depends on both the specific modules used and the geographical setting where they are deployed. For this research, PVsyst software was employed due to its capability to precisely evaluate important variables like energy output. This was particularly relevant in regions that receive abundant solar radiation, as the software can effectively simulate the solar system's behavior.

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[7] A future based on renewable energy. (22 C.E., November 28). *European Environment Agency*. https://www.eea.europa.eu/signals-archived/signals-2022/articles/a-future-based-on-renewable-energy accessed 20 October 2023.

In order to assess the efficacy of solar power, an exhaustive analysis was undertaken employing search terms like Solar Systems, PV Technology, Photovoltaic, Renewable Energy, and PVsyst. The objective of this research is to develop and simulate two distinct photovoltaic solar systems for EV Charging Stations and one Floating Solar Park, aiming to deliver both thermal and electrical energy. This is particularly relevant for addressing the essential demand for renewable energy sources in Hungary's urban regions.

Pvsyst Software

PVsyst, initially developed in Geneva, serves as a computational tool facilitating the analysis and operations of photovoltaic (PV) systems. This software aids in crafting the system's setup and allows for the estimation of energy yield. The resultant data hinges on the simulation of the system's sizing, which is predominantly influenced by the geographical positioning of the PV setup. Outcomes can encompass various simulation parameters, which can be represented in a range of temporal resolutions including monthly, daily, or hourly increments. Irwan et al. explained the "Loss Diagram" function offers insights into potential shortcomings within the system architecture [31]. Simulations utilizing PVsyst are executed through a series of successive steps.

Project Formulation

Within the databases of PVsyst, various sites and meteorological files are pre-integrated. However, it facilitates users in crafting customized projects predicated on the distinct site locations and corresponding meteorological data that are intended to be utilized, fostering a tailored approach to PV system planning [31].

Establishment of a System Variant

Subsequent to the initial phase, users generate a computational rendition of the project delineated in step 1. Razmjoo et al. explained this stage demands user input in defining vital facets such as module orientation, system layout, and loss parameters, paving the way for a more nuanced analysis in the later stages [27].

Implementation of the Simulation

This step entails the generation of diverse graphical representations and analytical reports pertaining to the PV system under scrutiny. Jagadale et al. [25] Users have the latitude to scrutinize the derived outcomes within the software interface, or they may opt to export the data to an alternative platform or retain the findings for in-depth assessment in subsequent evaluations [25].

Following the modeling using PVSyst, graphical representations and numerical data will be produced. Key metrics to consider include Sunpath, Normalized energy output, Performance Ratio, and the Loss Diagram. This section elaborates on the interpretations of these figures [25-26].

Sun path

In PVsyst, the "sun path" refers to a diagrammatic representation of the solar path, which is essentially the trajectory that the sun follows in the sky over the course of a day. This tool enables users to visualize the sun's position at various times throughout the day and across different seasons. It is crucial in understanding and analyzing the potential solar irradiance available at a specific location, which, in turn, assists in optimizing the orientation and tilt of the PV modules for maximum solar energy capture. The sun path diagram is fundamentally grounded in the geographical coordinates of the site (latitude, longitude) and can offer insights into potential shading issues from nearby obstacles. Consequently, this tool is instrumental in the accurate design and efficient planning of a solar power project, ensuring that the system is aligned to receive optimal sunlight exposure year-round. [25]

Normalized Energy Production

The graph shows the results proposed by the IEC 61724 standard. This is expressed in terms of standard variables defined in the standard. These variables are normalized for the system nominal power Pnum. These variables are allowed to compare systems of different kinds and sizes in different locations. Each bar is the reference system yield (Yr). This represents the energy that would be produced if the system were always producing with the nominal efficiency at standard test conditions. This is equivalent to the GlobInc value, the global incident on the collector plane. The base of the purple part is the energy at the output of the array (Ya). This corresponds to the EArray in the table. The purple area represents the array losses labelled (Lc) for collection loss. Lc = Collection Loss = Yr – Ya. The brown bars represent the energy injected into the grid (Yf). The green area represents the loss in the system (Ls), Ls = System Loss = Ya – Yf. In this case, the inverter loses. For more complex systems this may include the losses in the AC circuit if these are defined between the inverter and the injection point [25-26].

Performance Ratio

Each bar is the reference system yield (Yr). This represents the energy that would be produced if the system were always producing with the nominal efficiency at standard test conditions. This is equivalent to the GlobInc value, the global incident on the collector plane. The base of the purple part is the energy at the output of the array (Ya). This corresponds to the EArray in the table. The purple area represents the array losses labeled (Lc) for collection loss. The brown bars represent the energy injected into the grid (Yf). The green area represents the loss in the system (Ls). In this case, the inverter loses. For more complex systems, this may include the losses in the AC circuit if these are defined between the inverter and the injection point. The ratio of normalized produced energy to the reference energy is the performance ratio. The graph on the right shows the performance ratio for each month. In June, July, August months the performance ratio diminishes during the summer. This is due to higher operating temperatures of the PV array leading to higher temperature losses in the array. With shed like installations in middle latitudes the winter months may also experience a reduction in performance ratio due to the mutual shadings when the sun is low on the horizon.[26]-[27]

Balances and Result Table

The PVSyst incorporated with geographical site and shows some high-level summaries of the project system and results of this simulation variant the geographical site and meteorological data properties are fully defined in the report. It also incorporated with all the general parameters of the simulation for more complex systems these parameters may be extended over several conditions and different PV technologies. The general parameters include the system kind PV field orientation and the shading configuration used. The PV array characteristics include the modules and their arrangement in the array and the inverters if several subarrays are defined in the system. Array losses given an overview of all the settings involved in the calculation of the losses during the simulation.

Loss Diagram

In PVsyst's Loss Diagram, energy losses within a photovoltaic (PV) system are systematically delineated, showcasing the transition from initial solar irradiance received by the PV module to the final energy integrated into the grid or utilized by the load. This comprehensive breakdown categorizes losses into various segments, such as thermal discrepancies arising from temperature variations, Incident Angle Modifier (IAM) losses due to non-perpendicular sunlight angles, shading from obstructive elements, mismatch variances within PV module arrays, resistive ohmic losses in wiring, inverter inefficiencies during DC to AC conversion, availability issues stemming from system downtimes, and other potential system-specific losses. This detailed visual representation, punctuated by percentage allocations for each loss type, serves as an invaluable tool for academicians, system designers, and operators in their quest for system optimization and heightened efficiency. [25-27]

2.2 A Spatiotemporal Analysis and Forecasting of Electricity Generation-Mix in Hungary Using Artificial Analysis (ARIMA Model)

Chen et al. introduced a Bayesian temporal factorization approach for multidimensional time series prediction, providing insights into understanding temporal connections in complicated data [32]. Semenoglou et al. evaluated the accuracy of cross-learning time series forecasting methods, highlighting the necessity of domain-specific considerations when selecting forecasting approaches [33]. Athiyarath et al. undertook a comprehensive comparative investigation and analysis of time series forecasting methodologies, spanning classical statistical methods, machine learning models, and deep learning approaches [34]. Krollner et al. investigated financial time series forecasting with machine learning approaches, providing insights into predicting financial market movements [35].

Albers et al. emphasized task-driven evaluation and aggregation strategies in time series display, leading to effective data communication [36]. Parzen et al. [37] laid the groundwork for time series analysis with kernel density estimation, which remains prominent in statistics and time series modeling. Lai et al. [38], examined machine learning models in renewable energy projections, adding to sustainable energy planning. Munawar et al. [39] provided a framework for short-term solar power forecasting using machine learning algorithms, addressing issues in renewable energy integration. Klyuev et al. [40] put out a recent literature analysis on methods for projecting electric energy use, bringing insights into the newest advancements in the field. Newbold et al. [41] presented the ARIMA model design and the time series analytic method to forecasting, presenting a traditional perspective on time series modeling.

Selvan et al. [42] examined data analysis in context-based statistical modeling for predictive analytics, bringing insights into real-world applications. Harvey et al. [43] explored structural time series models, presenting a complete grasp of this class of models. De Gooijer et al. [44]

reflected on 25 years of time series forecasting, outlining important advancements in the discipline. Torres et al. [45], did a survey of deep learning for time series forecasting, stressing the relevance of neural networks in this domain. Ahmed et al. [46], empirically compared machine learning models for time series forecasting, contributing to the identification of relevant strategies in diverse applications. These works give a wide view of time series forecasting, including methodology, applications, and recent discoveries. We learned from these papers' essential insights and methodologies in time series analysis and prediction for this work.

2.3 Energy Policy

Energy policy has long been a subject of intense debate, research, and policymaking, addressing the challenges of sustainability, security, and economic viability. This review aims to encapsulate key findings, theories, and concerns in the domain of energy policy.

The global demand for sustainable energy solutions has been on the rise, driven by concerns of climate change and environmental degradation. Green et al. (2018) argues that the shift towards renewable energy sources, such as wind, solar, and hydro, is imperative to reduce carbon emissions and mitigate global warming [51]. However, Johnson et al. (2019) cautioned that the intermittent nature of some renewables necessitates advances in energy storage and grid management [52].

Energy security has been a pressing concern for many nations, especially those dependent on imports. Walker (2017) highlights the geopolitical implications of energy security, where nations can wield energy as a political tool [53]. In contrast, Davies et al. (2020) emphasize the need for diversifying energy sources and strengthening intra-regional energy cooperation to enhance security [54].

The economic aspects of energy policy can't be ignored. As Thompson (2021) points out, the transition to renewables can be costly in the short term but promises long-term economic benefits [55]. Furthermore, the decline in fossil fuel prices, as noted by Rodriguez (2022), can influence energy policy decisions and potentially slow down the transition to green energy [56].

Innovation plays a crucial role in shaping energy policy. Lee et al. (2018) discusses the emergence of smart grids, which enable better management and distribution of energy [57]. On the other hand, Kumar (2019) highlights advancements in nuclear fusion as a potential game-changer for future energy policies [58].

Engaging the public and understanding societal impacts is crucial for successful energy policy implementation. White et al. (2020) provide insights into the societal challenges faced during the deployment of large-scale wind farms. They argue for a more participatory approach, ensuring communities play a role in energy policy decisions [59].

Chapter 3: Feasibility of Energy Mixing in Urban Area in Hungary

3.1 Introduction

Throughout its history, Hungary's energy sector has been primarily characterised by the prominent utilisation of fossil fuels and nuclear energy sources. The significant role of fossil fuels in its energy portfolio is evident, but equally noteworthy is the country's inclination towards nuclear energy, highlighted by the Paks Nuclear Power Plant's critical contribution to its electricity grid. Nestled by the Danube River, this facility symbolizes Hungary's trust in nuclear power as a primary and consistent energy resource. Although there's a global shift towards green energy, Hungary underscores the importance of maintaining and possibly augmenting its nuclear prowess, as seen in discussions surrounding the Paks facility's expansion. Various factors drive this direction, including energy security, existing infrastructural investments, and the need for a constant energy source.

Up to the start of 2022, while Hungary has witnessed some renewable initiatives, the bulk of its energy blend remains rooted in traditional sources, mirroring a deliberate approach in its energy roadmap. Hungary, positioned in the heart of Europe, has the capability to harness a diverse range of renewable energy sources, even within its urban spaces. Benefitting from approximately 2,000 hours of sunshine annually, urban areas offer considerable scope for solar installations on rooftops and facades. While the country's topography might not be ideal for large-scale wind farms within cities, the adoption of compact, vertical-axis turbines could weave seamlessly into the urban fabric. The Pannonian Basin beneath Hungary provides a unique opportunity for geothermal energy, which could be utilized for district heating in metropolitan regions.

Although Hungary is traversed by significant rivers like the Danube and Tisza, its potential for hydropower is constrained by its largely flat topography, which lacks the elevation changes ideal for hydropower generation. Additionally, the river flows are inconsistent for steady power output, and the environmental implications, especially potential harm to vital wetland ecosystems, further deter large-scale projects. Economic viability remains questionable, especially when juxtaposed with more promising renewable energy options like solar and wind. The Danube's cultural and historical significance, coupled with its multifaceted use for agriculture, transportation, and recreation, makes large interventions potentially contentious. Lastly, the transboundary nature of the Danube necessitates complex coordination with neighboring countries, adding layers of challenge to hydropower initiatives. Though, the agricultural backbone of the country suggests potential for biomass-based energy, in Hungary's urban settings, biomass-based energy faces several challenges.

The combustion of biomass can exacerbate urban air pollution, releasing harmful pollutants that pose health risks. Given the spatial constraints of cities, storing vast amounts of biomass feedstock becomes problematic. Moreover, transporting this feedstock to urban centers adds logistical difficulties and elevates the overall carbon footprint. Organic waste, a potential biomass source, often has competing urban uses like composting. Economically, urban infrastructure and storage costs can make biomass less attractive, especially with the declining costs of other renewables like solar and wind. Residents might also express concerns about odors, potential health hazards, and aesthetic disruptions associated with biomass plants.

Furthermore, the efficiency of biomass energy might not meet the high and consistent demands of urban energy consumption. However, the real challenge lies in updating the grid infrastructure to handle intermittent renewable inputs and in securing consistent policy and financial support. As Hungary aligns more with EU green directives, the pivot to urban renewable integration appears not only feasible but also imperative. In urban areas of Hungary, solar and geothermal energy sources present particularly promising potentials. Firstly, solar energy harnesses the abundant sunlight the country receives, especially during summer months.

With the advancements in photovoltaic technology and the decreasing cost of solar panels, urban rooftops, walls, and even some pavements can be transformed into energy-generating assets, optimizing space in densely populated areas. Geothermal energy, on the other hand, leverages Hungary's unique geographical advantage, as the country is situated over the Pannonian Basin, known for its substantial geothermal potential. This allows urban areas to tap into the Earth's natural heat for both direct heating and electricity generation. Moreover, geothermal systems, once installed, occupy minimal surface space and have a low visual footprint, making them ideal for urban settings. Both solar and geothermal energy offer sustainable and cleaner alternatives, aligning with Hungary's goals to reduce carbon emissions and transition towards more sustainable urban development.

3.2 Solar Energy

Solar energy in Hungary has gained significant attention in recent years. An analysis reveals a focused attempt to understand the current and prospective scenarios of solar energy in the nation, particularly in the context of the Visegrád Group countries [9]. The establishment of solar power stations in Hungary involves a series of processes culminating in the construction of these stations, highlighting both the commitment to and the challenges faced in embracing this renewable energy source [10]. The global advancements in solar PV energy and their policies underscore the strides made by the top ten solar PV power-producing nations, placing Hungary in the broader context of global solar initiatives [11]. As renewable energy research continues, the modelling and processes involved in these energy sources further solidify the foundation for sustainable energy solutions in the future [12]. While the focus on solar energy in Hungary is evident from these studies, a broader look at renewable energy trends suggests an interdisciplinary approach that integrates environmental, agricultural, and energy perspectives [13]

3.2.1 Methodology

The effectiveness of a photovoltaic (PV) setup depends on both the specific modules used and the geographical setting where they are deployed. For this research, PVsyst software was employed due to its capability to precisely evaluate important variables like energy output. This was particularly relevant in regions that receive abundant solar radiation, as the software can effectively simulate the solar system's behavior.

In order to assess the efficacy of solar power, an exhaustive analysis was undertaken employing search terms like Solar Systems, PV Technology, Photovoltaic, Renewable Energy, and PVsyst. The objective of this research is to develop and simulate two distinct photovoltaic solar systems for EV Charging Stations and one Floating Solar Park, aiming to deliver both thermal and electrical energy. This is particularly relevant for addressing the essential demand for renewable energy sources in Hungary's urban regions.

In this study, we introduce two grid-integrated photovoltaic setups designated for electric vehicle (EV) charging stations and a separate Floating Solar Park. Utilizing a inverter is essential in solar energy configurations because the solar panels produce direct current (DC) electricity, whereas the end-users necessitate alternating current (AC) electricity.

Consequently, key components such as photovoltaic modules, fuse enclosures, inverters, utility meters, and electrical grid connections are factored into the design of the grid-connected photovoltaic arrangements. The fundamental role of these photovoltaic modules is to generate DC electrical output. Inverters within these systems serve to transform the DC electricity into AC form, which is subsequently fed into the electrical grid through specialized utility meters and fuse boxes. These inverters are engineered to continuously emit a sinusoidal output and are configured to function in synchrony with the existing electrical grid.

Figure 1 provides an outline of the tentative model, which serves as a foundation and can be modified or enhanced to better suit real-world conditions, depending on the final requirements and constraints.

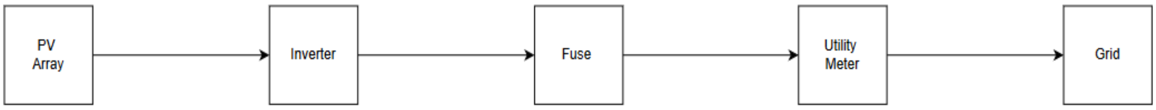

Figure 1: Grid Connected PV System Model [Ownwork,Software:Adobe Photoshop]

Mathematical Description of the Proposed System

This section delineates the fundamental equations employed for the scrutiny and simulation-based modelling of solar energy facilities using PVsyst software, as corroborated by references these equations elucidate the computational methodologies and how outcomes are derived [23-24]. The three categories of inverters routinely utilized in photovoltaic systems are cited in reference [25]:

1. String inverters
2. Central inverters
3. Micro inverters

String inverters are constrained in terms of their capacity but offer the benefit of being both compact and straightforward to install and manage.

A transformer serves as an apparatus that facilitates the transfer of electrical energy from one alternating current circuit to one or more additional circuits, altering the voltage levels without modifying the frequency.

Moreover, for a comprehensive assessment of solar photovoltaic (PV) plant efficacy, multiple metrics need to be computed. These include array yield (YA), reference system yield (YR), final system yield (YF), performance ratio (PR), and the capacity utilization factor (CUF) [25].

Array yield is conceptualized as an efficiency matrix, indicating the daily direct current (DC) energy output normalized by the nominal power of the array (kWh/KWp/day). Essentially, array yield serves as a measure that encapsulates the temporal (daily, monthly, and yearly) DC energy production from the photovoltaic array, scaled to its rated power.:

$$Y_A = \frac{E_{DC}}{P_O} \quad \text{.................................} \ (1)$$

The reference yield serves as an indicator of the peak sun-hours per day and is determined by dividing the aggregate in-plane solar insolation (kW/m^2) by the standard reference irradiance (kW/m^2) associated with the array. In standard test conditions (STC), this reference irradiance is conventionally set at 1000 W/m^2 and signifies the requisite energy level to generate the array's nominal power (P_nom) over the duration of one hour. In the formula, YR denotes the term for incident energy (kWh/m^2/day) in the array's plane [26].

$$Y_R = \frac{H_t(kWh/m^2)}{I_A(kW/m^2)} \quad \text{.................................} \ (2)$$

The concept of Final Yield pertains to the duration needed for the photovoltaic system to generate its net energy output at its specified rated power. This metric is derived by dividing the net alternating current (AC) energy produced by the system, whether measured on an annual, monthly, or daily scale, by the peak power capability of the photovoltaic panels.[26]:

$$Y_F = \frac{E_{AC}}{P_P} \quad \text{.................................} \ (3)$$

The Performance Ratio is determined by taking the final yield and dividing it by the reference yield. This quotient serves as an indicator of system efficiency by revealing the proportion of energy losses attributable to an array of elements, including panel deterioration, contamination, shadowing, thermal effects, and other intrinsic inefficiencies. Under practical conditions, the performance ratio offers a comparative measure of the actual versus potential effectiveness of a solar photovoltaic installation. [26-27]:

$$PR = \frac{Y_F}{Y_R} \quad \text{……………………………... (4)}$$

The capacity utilization factor (CUF) is characterized as the proportion of the annual energy production of a solar PV system to the potential maximum output that could be achieved during the same timeframe, given its rated capacity. [26-27]:

$$CUF = \frac{E_{AC}}{P_P} \times 8760 \quad \text{……………………………. (5)}$$

The efficiency of a photovoltaic (PV) panel, denoted as ηPV, can be determined using a specific formula [27].

The efficiency of the inverter in a solar photovoltaic system, represented as ηinv, is computed by taking the alternating current (AC) power output generated by the inverter and dividing it by the direct current (DC) power output from the photovoltaic array [27].

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}} \times 100\% \quad \text{……………………………. (6)}$$

In a solar photovoltaic installation, the overall system efficiency is determined by dividing the electrical power generated by the array by the cumulative in-plane solar insolation. This equation provides a metric for the system's effectiveness in converting solar energy into electrical power [27].

$$\eta_s = \frac{E_{AC}}{G_i \times A_{PV}} \times 100\% \quad \text{……………………………. (7)}$$

The efficacy of a solar photovoltaic facility is affected by a multitude of loss factors that can manifest at different stages within the system. For a precise quantification of these losses, it is imperative to compute both the array capture loss (LA) and system loss (LS).

Array capture loss (LA) encompasses thermal losses due to elevated photovoltaic cell temperatures, dust accumulation on the arrays, fluctuating irradiance levels, localized shading, deviations in maximum power point tracking, and internal inconsistencies. Consequently, array capture loss (LA) can be ascertained by taking the array yield and deducting the reference yield [25-27].

$$L_A = Y_R - Y_A \quad \text{……………………………. (8)}$$

System loss (LS) denotes the losses incurred in both direct current (DC) and alternating current (AC) cabling, ascertained by deducting the array yield from the final system yield. This encompasses losses attributable to inverters in grid-tied configurations or to batteries in independent systems [26-27].

$$L_S = Y_A - Y_F \quad \text{……………………………. (9)}$$

3.2.2 System Modeling

Our project plan is to enhance the solar capacity in Budapest. For this reason, we try to investigate which type of solar energy production system has not been launched yet in the urban reason of Hungary, e.g., Budapest, Debrecen, Gyor, Pecs, and Lake Balaton neighborhoods. It is experienced that Hungary does not have a hybrid solar system, a solar EV parking station, or a floating solar park. The Hungarian government has put restrictions on the connection of small household-scale power plants to the grid, or, on the other hand, hybrid systems. If we consider the diplomatic complexity of the hybrid system, Hungary could still launch solar EV charging stations and a few numbers of Floating Solar parks.

The far-reaching advantage of solar EV charging stations is these charging stations are placed mainly in car parking areas and these car parking areas are in open spaces, except car parking where open spaces are not used for any purpose. So, if we install solar systems here in these places then we can charge a good number of Electrical vehicles every day, which is more sustainable and environmentally friendly, and most importantly, we could generate energy from unused spaces.

Floating solar or floating photovoltaics (FPV) are terms used to describe solar panels that are installed on floating constructions. These floating systems tend to be used in reservoirs, lakes, and other expansive aquatic environments. One of the main advantages of FPV is its utilization of unutilized surface area on water, hence circumventing the need for expensive land resources. The reduction of water evaporation can be achieved by implementing partial coverage of water basins, with the effectiveness of this approach dependent on the prevailing climate conditions and the extent of surface coverage. FPV technology has the potential to yield significant advantages in terms of safeguarding natural lakes and other freshwater bodies that face the threat of depletion. The cooling effect of water as a host to the PV panels leads to an energy gain that ranges from 5% to 15% [28]. Spacious buoyant structures can effortlessly pivot both horizontally and vertically to facilitate solar tracking, akin to the behavior of sunflowers. This function can enhance energy capture by 15-25%, without necessitating the intricate mechanical systems found in terrestrial PV facilities.

Moreover, the expense of installing a tracking mechanism on a floating PV facility is comparatively low, establishing it as an economical method for optimizing solar energy yield. Another important positive side is the shadow effect is mostly zero per cent. Based on our empirical research and on-site assessments, Hungary harbours substantial potential for the establishment of Floating Photovoltaic (FPV) installations in various promising locales. Notable among these are Lake Balaton, encompassing an expansive area of 592 km^2, thereby representing the largest lake within the nation's borders. Moreover, the River Tisza stretches over 597 km^2 within the Hungarian territory, currently housing two hydroelectric dams: the Kisköre-based Tisza Dam with a capacity of 28 MW, and the Tiszalök Dam contributing 12.9 MW to the electrical grid. Furthermore, the River Hármas-Körös is home to the Békésszentandrás dam, a facility with a generation potential of 2 MW, presenting additional opportunities for the integration of FPV systems. These sites represent feasible starting points for the proliferation of FPV technology, fostering a synergy between existing hydroelectric infrastructures and emergent solar capabilities.

Site Survey

To introduce Solar EV charging stations in Hungary we have chosen two different charging stations. The first, situated at Clark Adam Ter (47°29'50.9"N;19°02'27.8"E), will potentially feature a ground mountain design, as per our initial site assessment. In contrast, the second charging station which is in the Alkotas Utca (47°29'39.8"N;19°01'26.9"E) is poised for a rooftop model integration, fostering an expansion of Hungary's solar infrastructure while making prudent use of existing urban spaces. Lastly, proposal of the implementation of a Floating Photovoltaic (FPV) solar park at the catchment area of Tisza Dam, Kisköre, as Floating Solar is often installed on existing *hydropower* which reduces costs by using the existing transmission lines and distribution infrastructure and increases efficiency. FPV can play a significant role in conserving bodies of fresh water that are at risk. For example, a case study of Lake Mead showed that covering 10% of the lake with FPV would generate enough electricity to serve both Las Vegas and Reno while also conserving water. At 50% coverage, FPV could produce over 127 TWh of clean solar energy and save 633.22 million m3 of water, enough to retire 11% of coal-fired power plants in the United States and provide water for more than five million Americans each year.[8] The goals of this study are to:

- Evaluate the given site's solar energy potential.
- Develop a PV system layout based on load requirements.
- Calculate the performance ratio and losses via PVsyst software simulation.

Case-1: Ground-Mounted Solar EV Charging Station

This EV charging station is located within a designated parking area. The total area of this parking lot is around 1238.71m². Before any panel is mounted, careful consideration is given to the specifics of the location, ensuring that the installation of the ground-mounted solar panel structure does not interfere with the existing functionality of the space, specifically the smooth movement and parking of cars. It's imperative that the new structures harmonize with the existing layout, providing added value without hindrance. After a comprehensive study, an optimal area of 273 m² has been earmarked for the installation of the solar panel structures. At the core of this project lies a deep commitment to environmental sustainability. This venture seeks not to alter the existing structure but to enhance it, leveraging the

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[8] Mo'men. (2016, April 16). Floating Solar Power Plants. *Linkedin*. https://www.linkedin.com/pulse/floating-solar-power-plants-mo-men-rabaa/ accessed 27 October 2023.

untapped potential of solar energy. In doing so, it promises not only to preserve the existing architecture but to transform it into a hub of green energy, consequently contributing to a significant reduction in CO2 emissions.

Project Overview:

- Location: Clark Adam Ter (47°29'50.9"N;19°02'27.8"E)
- Total PV capacity: 50.46 kWp DC
- PV nom. Power/unit: 670 Wp
- No of Panels: 88
- No of Inverters: 1
- Inverter Size: 50 kW
- Pnom:1.18
- Tilt/Azimuth: 35° / 0 °
- Area: 273 m^2.
- Yearly Total Generation: 70120 kWh/year

Layout:

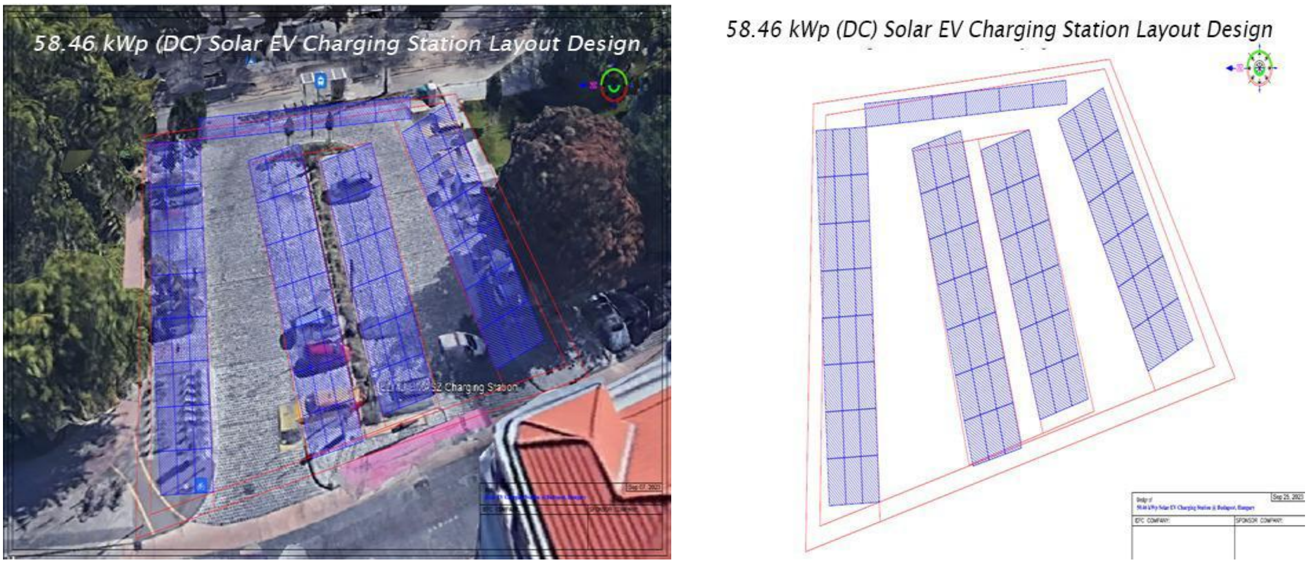
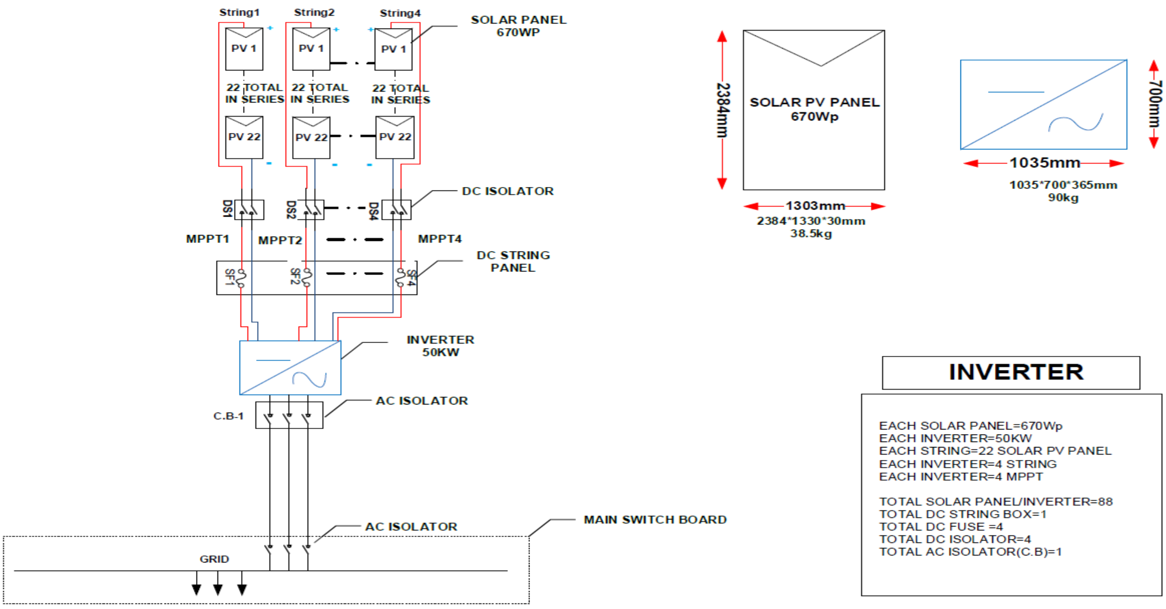


Figure 2: Ground-Mounted Model Solar EV Charging Station Layout, [Own Work, Software: AutoCAD]

Wiring Diagram:



EACH SOLAR PANEL=670Wp
EACH INVERTER=50KW
EACH STRING=22 SOLAR PV PANEL
EACH INVERTER=4 STRING
EACH INVERTER=4 MPPT

TOTAL SOLAR PANEL/INVERTER=88
TOTAL DC STRING BOX=1
TOTAL DC FUSE =4
TOTAL DC ISOLATOR=4
TOTAL AC ISOLATOR(C.B)=1

Figure 3: Wiring Diagram of Ground-Mounted Model Solar EV Charging Station [Own work, Software: AutoCAD]

Single Line Diagram (SLD) Design:

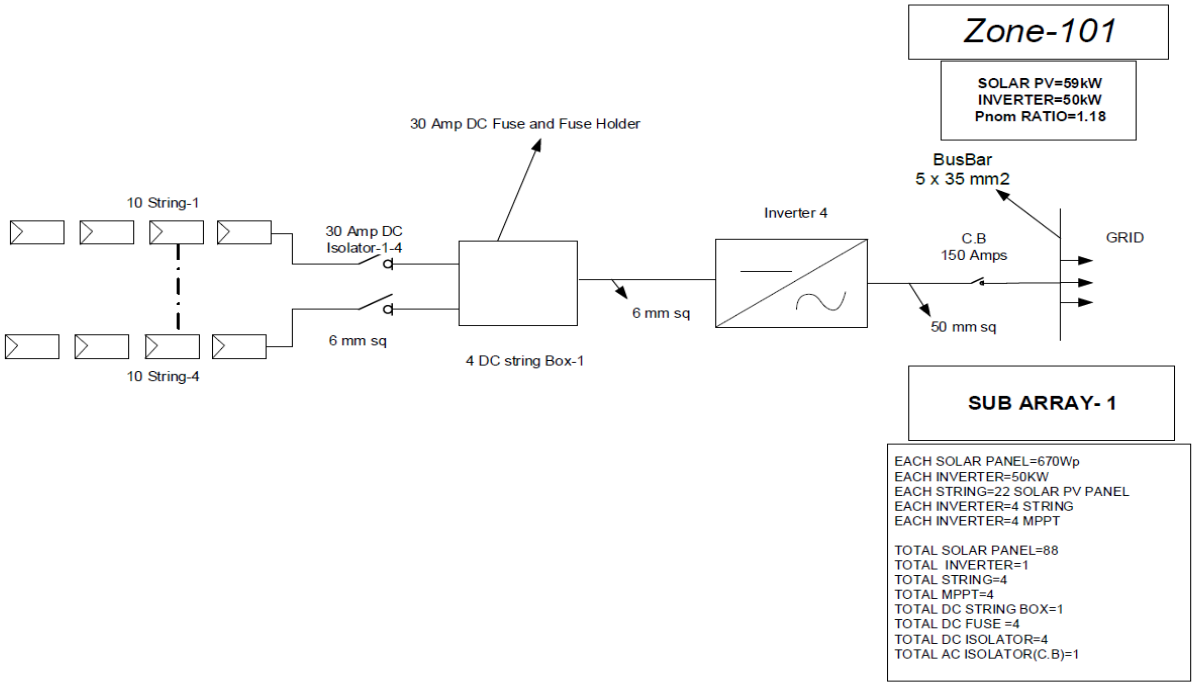


Figure 4: SLD Design of Ground-Mounted Model Solar EV Charging Station [Own work, Software: AutoCAD]

Case-2: Roof Top Model Solar EV Charging Station

This EV charging station is located in a Commercial Fuel station. Utilizing the available rooftop space, which measures approximately 480.37 m², presents a financially and technically feasible solution, circumventing the necessity for extensive mechanical structures associated with ground-mounted models. Comparatively, while the ground-mounted model necessitates additional financial investment and design intricacies due to its requirement for a mechanical support structure, the rooftop model offers a more streamlined approach. Eliminating the need for extensive mechanical structures not only offers financial advantages but also reduces the installation's complexity. In the context of establishing a solar EV charging station, the prevailing models for consideration are predominantly bifurcated into ground-mounted and rooftop configurations, with the latter presenting a more feasible option in this scenario.

Project Overview:

- Location: Alkotas Utca (47°29'39.8"N;19°01'26.9"E)
- Total PV Capacity: 29.48 kWp DC
- PV nom. Power/unit: 670 Wp
- No of Panels: 44
- No of Inverters: 1
- Inverter Size: 25 kW
- Pnom: 1.18
- Tilt/Azimuth: 35° / 0 °
- Area: 137 m²
- Yearly Total Generation: 35114 kWh

Layout:

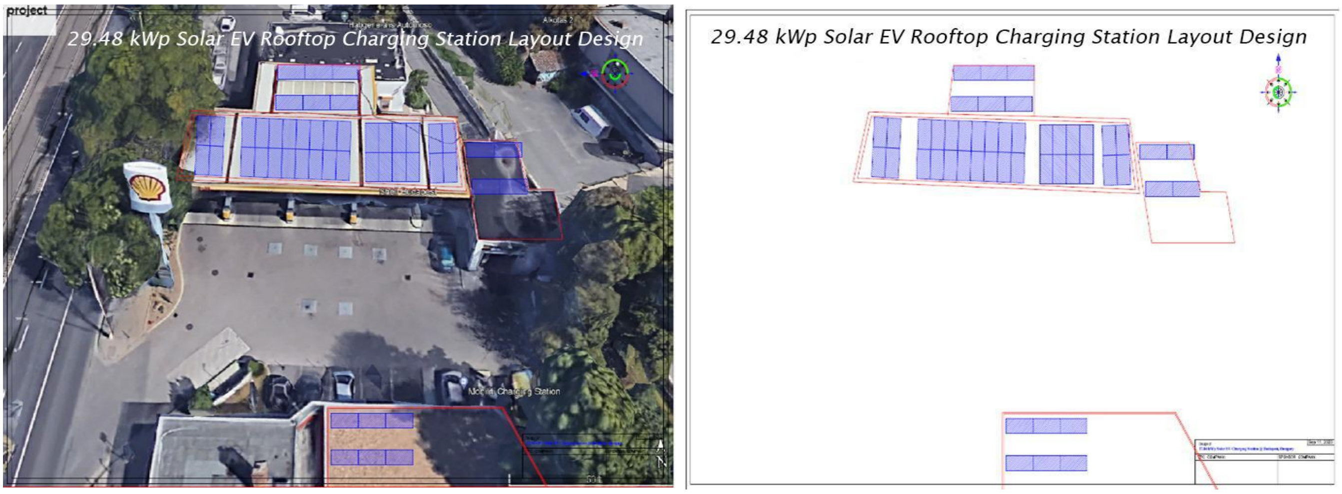


Figure 5: Roof Top Solar EV Charging Station Layout [Own work, Software: AutoCAD]

Wiring Diagram:

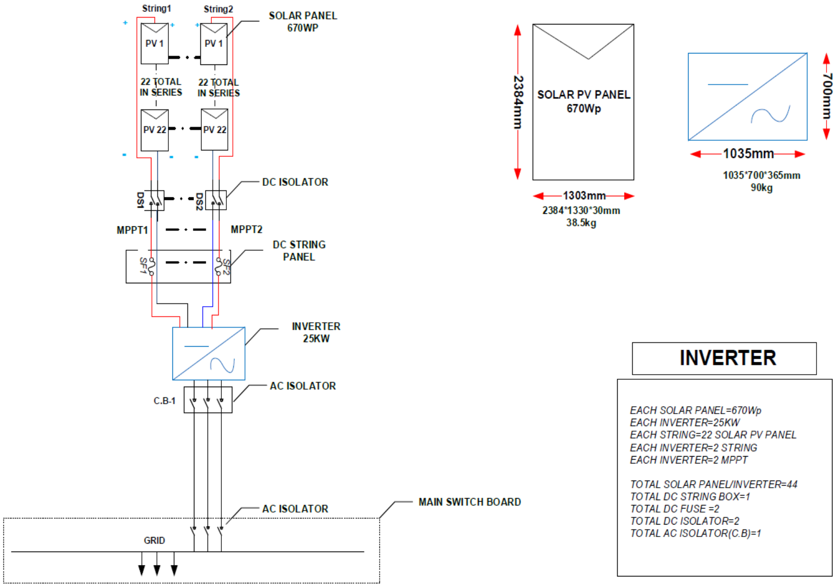


Figure 6: Wiring Diagram of Roof Top Model Solar EV Charging Station [Own work, Software: AutoCAD]

Single Line Diagram (SLD) Design:

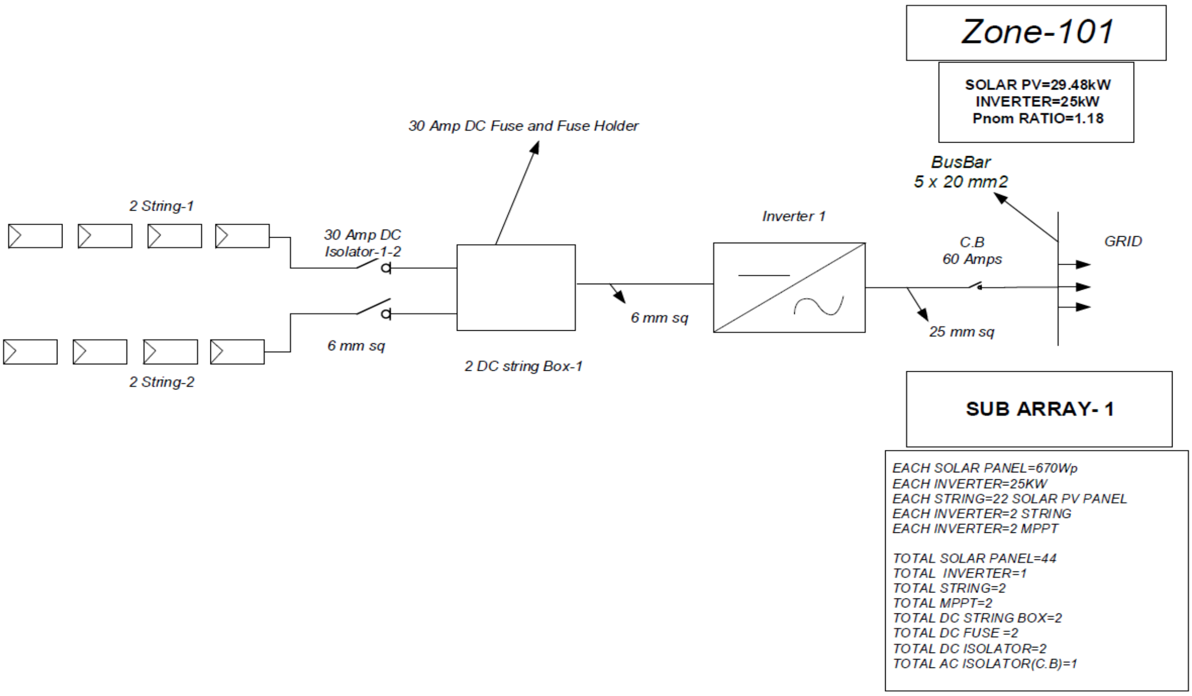


Figure 7: SLD Design of Roof Top Model Solar EV Charging Station [Own work, Software: AutoCAD]

Case 3- Floating Solar Park on Tisza Dam, Kisköre **:**

Despite being a landlocked country devoid of coastal regions, Hungary demonstrates immense potential to pioneer the establishment of a floating solar park. Remarkably, the nation is endowed with significant water bodies that can facilitate this innovation. For instance, Lake Balaton covers an area of 592 km², coupled with the river Tisza, which spans over 597 km² within Hungary, already accommodating two hydroelectric dams. Additionally, the regions encompassing the River Danube and the River Hármas-Körös, which also features a dam, present viable sites for this endeavor. Lake Valence further augments the list of potential hosts for a floating solar park. Floating Solar is generally installed on existing hydropower or on the catchment area of dam, which is cost effective by using the existing transmission lines and distribution infrastructure and increases efficiency. For FPV in this project Tsiza Dam has been considered. The Tisza Dam, located in Kisköre within Heves County, stands as a testament to the region's commitment to harnessing renewable energy. From 2000 to 2022, the average monthly electricity consumption in Heves County was recorded at 194.75 kWh. This 2.5 MWp Floating Photovoltaic (FPV) park, capable of producing approximately 2,850,983 kWh annually (237,581kWh/monthly). From 2000 to 2022, the Tisza Dam in Kisköre, Heves County, witnessed an average monthly electricity consumption of 194.75 kWh. With the estimated annual energy output of this solar park, nearly 1,220 households within Heves County could be fully powered.

Project Overview:

- Location: Tisza Dam, Kisköre (47°29'35.3"N 20°30'56.1"E)
- Total PV Capacity: 2.5 MWp DC
- PV nom. Power/unit: 670 Wp
- No of Panels: 3780
- No of Inverters: 21
- Inverter Size: 100 kW
- Pnom:1.20

- Tilt/Azimuth: 10° / 0 °

- Area: 0.012 km² (11742 m²).

- Yearly Total Generation: 2,850,983 kWh

Layout:

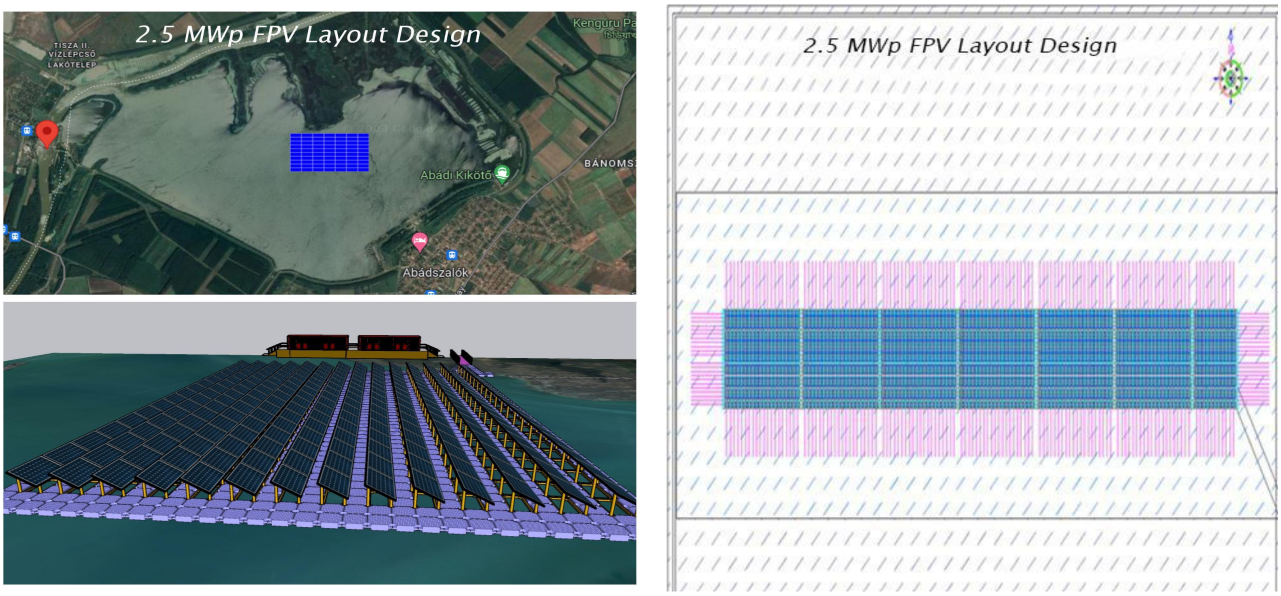
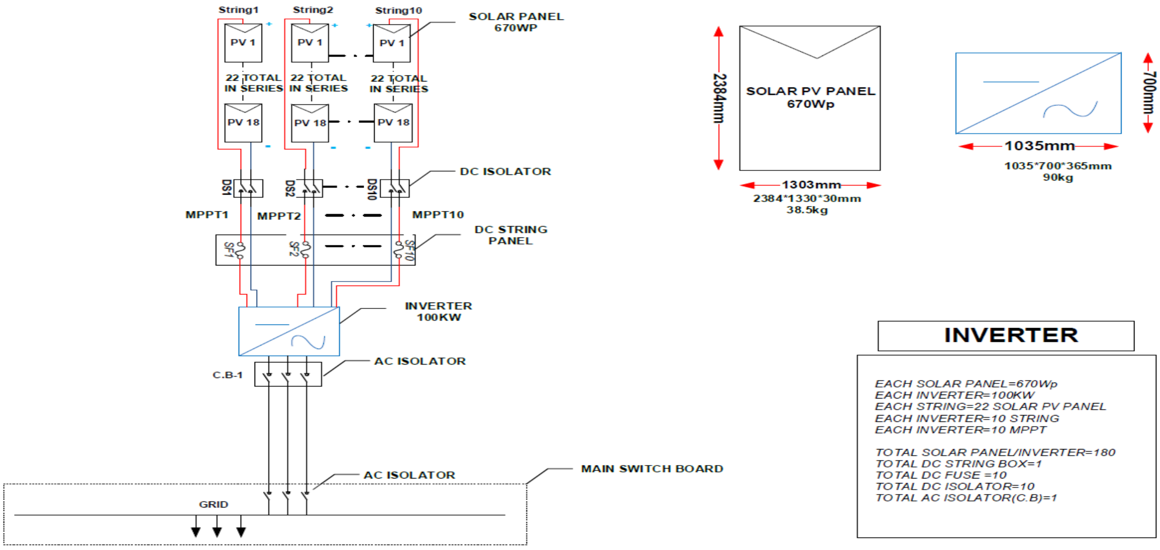


Figure 8: Floating Solar PV System Model in Tisza Dam, Kisköre [Own Work, AutoCAD]

Wiring Diagram:



INVERTER

EACH SOLAR PANEL=670Wp
EACH INVERTER=100KW
EACH STRING=22 SOLAR PV PANEL
EACH INVERTER=10 STRING
EACH INVERTER=10 MPPT

TOTAL SOLAR PANEL/INVERTER=180
TOTAL DC STRING BOX=1
TOTAL DC FUSE =10
TOTAL DC ISOLATOR=10
TOTAL AC ISOLATOR(C.B)=1

Figure 9: Wiring Diagram of Floating Solar Park in Tisza Dam, Kisköre [Own work, Software: AutoCAD]

Single Line Diagram (SLD) Design:

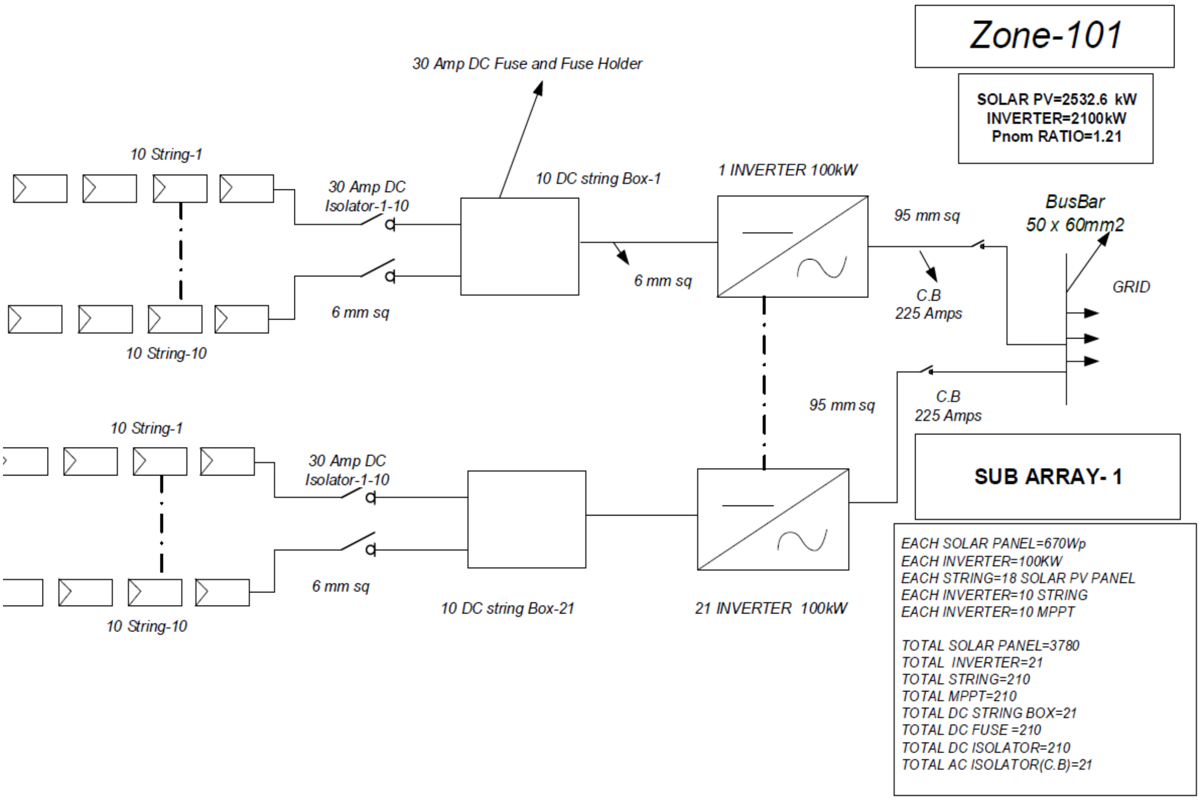


Figure 10: SLD Design of Floating Solar Park in Tisza Dam, Kisköre [Own work, Software: AutoCAD]

3.2.3 Results

Case 1: Ground-Mounted Solar EV Charging Station at Clark Adam Ter, Budapest

Sun path or Solar Horizon

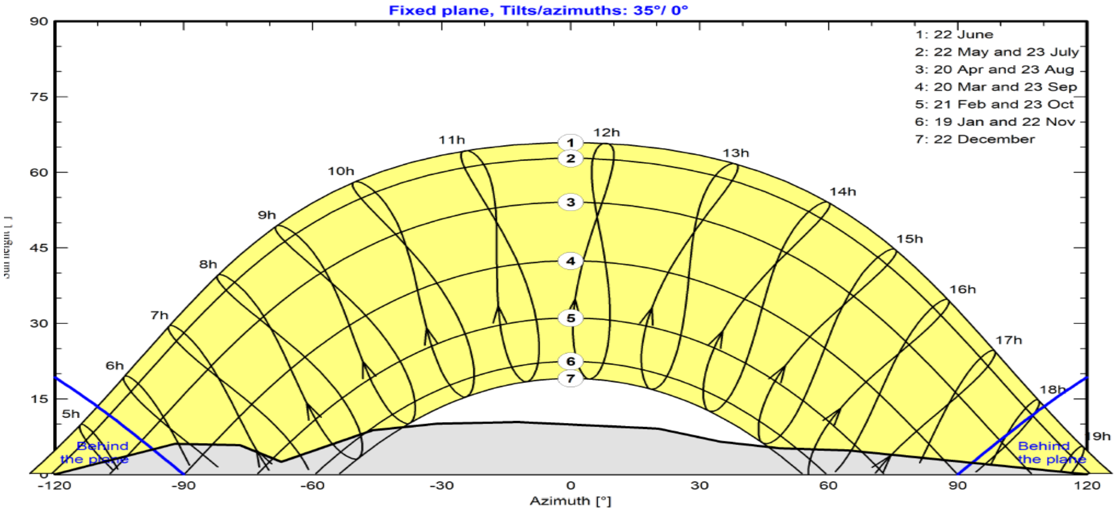


Figure 11: Solar Horizon at Clark Adam Ter, Budapest, [Own work, Software: PVSyst]

Monthly normalized production:

Produced Energy

70120 kWh/year

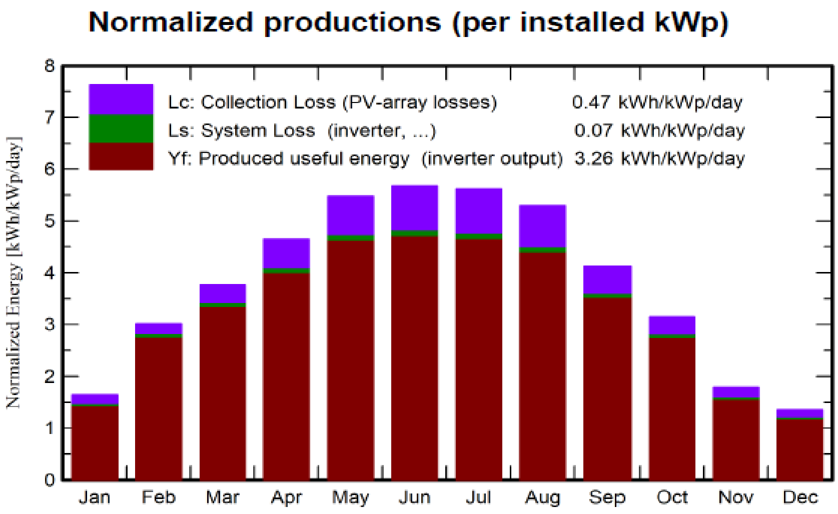


Figure 12: Monthly normalized production Ground Mounted Solar EV Charging Station in Clark Adam Ter, Budapest [Own work, Software: PVSyst]

Monthly performance ratio:

Specific production	1189 kWh/kWp/year
Performance Ratio PR	85.75 %

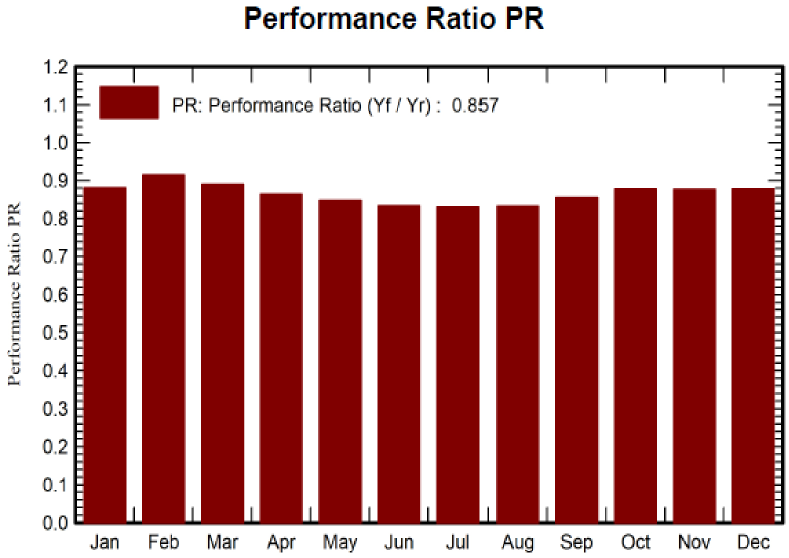
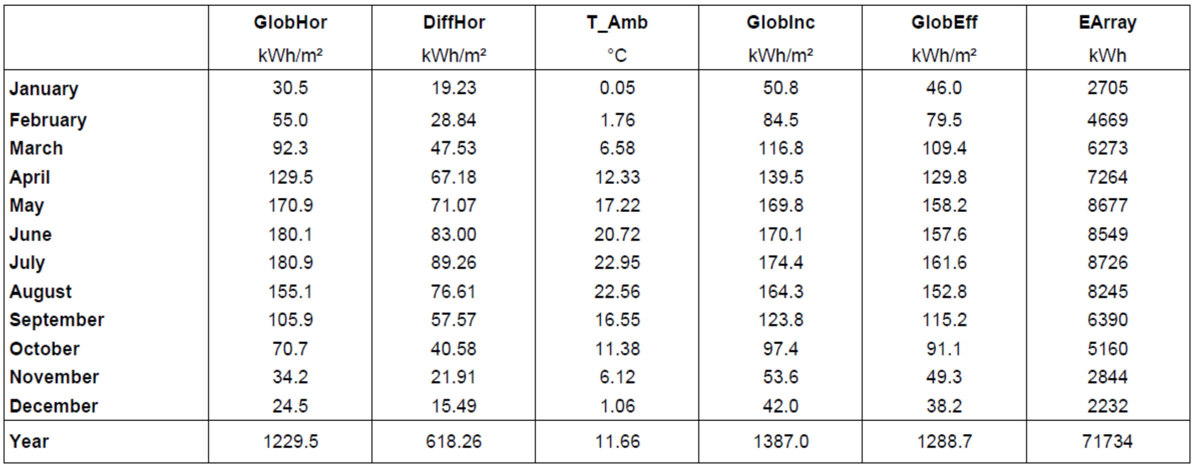


Figure 13: Monthly Performance Ratio for a Ground Mounted Solar EV Charging Station in Clark Adam Ter, Budapest [Own work, Software: PVSyst]

Balances and Main Results Month-wise:



	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh
January	30.5	19.23	0.05	50.8	46.0	2705
February	55.0	28.84	1.76	84.5	79.5	4669
March	92.3	47.53	6.58	116.8	109.4	6273
April	129.5	67.18	12.33	139.5	129.8	7264
May	170.9	71.07	17.22	169.8	158.2	8677
June	180.1	83.00	20.72	170.1	157.6	8549
July	180.9	89.26	22.95	174.4	161.6	8726
August	155.1	76.61	22.56	164.3	152.8	8245
September	105.9	57.57	16.55	123.8	115.2	6390
October	70.7	40.58	11.38	97.4	91.1	5160
November	34.2	21.91	6.12	53.6	49.3	2844
December	24.5	15.49	1.06	42.0	38.2	2232
Year	1229.5	618.26	11.66	1387.0	1288.7	71734

Table 1: Monthly Balances and Results for Ground Mounted Solar EV Charging Station in Clark Adam Ter, Budapest [Own work, Software: PVSyst]

Loss Diagram:

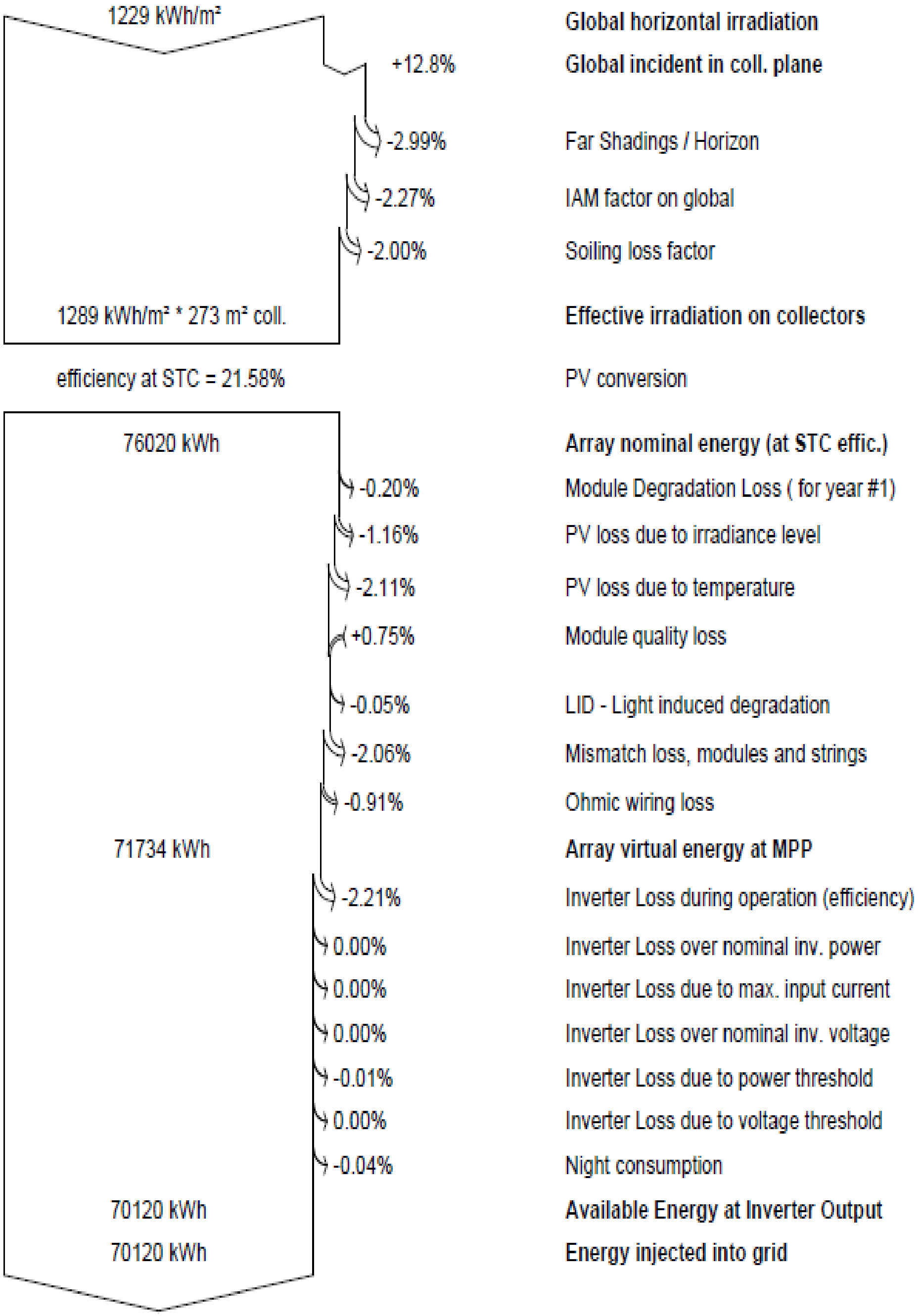
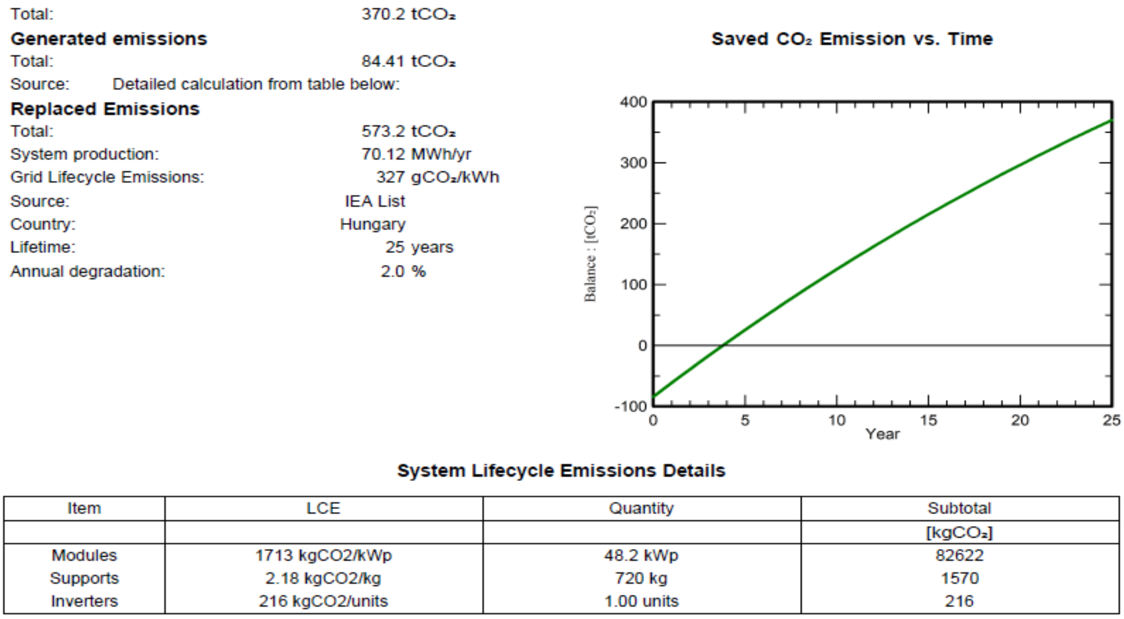


Figure 14: Loss diagram of Ground Mounted Solar EV Charging Station in Clark Adam Ter, Budapest [Own work, Software: PVSyst]

CO2 Emission Balance:



Total: 370.2 tCO_2

Generated emissions

Total: 84.41 tCO_2

Source: Detailed calculation from table below:

Replaced Emissions

Total:	573.2 tCO_2
System production:	70.12 MWh/yr
Grid Lifecycle Emissions:	327 gCO_2/kWh
Source:	IEA List
Country:	Hungary
Lifetime:	25 years
Annual degradation:	2.0 %

System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	48.2 kWp	82622
Supports	2.18 kgCO2/kg	720 kg	1570
Inverters	216 kgCO2/units	1.00 units	216

Figure 15: CO2 Emission Balance Ground Mounted Solar EV Charging Station in Clark Adam Ter, Budapest [Own work, Software: PVSyst]

Findings:

The normalized energy production of this Ground Mounted Solar Photovoltaic (PV) system (Figure 12) throughout the year, measured in kWh per kWp installed capacity per day. Each month's bar is divided into three sections: collection loss (blue) indicating energy lost due to solar panel inefficiencies, system loss (purple) from components like inverters, and the useful energy output (red). On average, the system experiences 0.47 kWh/kWp/day in collection losses, 0.07 kWh/kWp/day in system losses, and produces 3.26 kWh/kWp/day of useful energy. The Performance ratio (Figure 13) of this system is 85.75 %.

From Table 1 we get, the Global Horizontal Irradiance (GlobHor) starts at 30.5 kWh/m² in January and peaks at 180 kWh/m² in both June and July, reflecting maximum sunlight during summer. Conversely, December has the lowest GlobHor value at 24.5 kWh/m². The Diffuse Horizontal Irradiance (DiffHor) peaks in July at 89.26 kWh/m². The Global Incident Irradiance (GlobInc) and Global Effective Irradiance (GlobEff) reach their maxima in July, with values of 174.4 kWh/m² and 161.6 kWh/m², respectively. The energy output from the solar array (EArray) also peaks in July at 8,726 kWh, emphasizing the strong solar activity during the summer. On the other hand, December exhibits the least solar energy output with only 2,232 kWh.

From Figure 13 we can get the understanding of losses. After the deduction of losses this system is capable to produce 70,120 kWh/year (193 kWh/Day). So, through this PV system Every day 3-5 Electric Vehicle could be powered up as Most EV models take 35-60 kWh to achieve a full charge. Lifetime of this project is 25 years, so, in this life cycle 27,375 to 45,625 Electric Cars could powered up. Not only this from this system (Figure 15) we can reduce 370.2 metric tons of CO2 emissions compared to conventional energy sources in 25 years.

Case 2: Roof Top Model Solar EV Charging Station at Alkotas Utca, Budapest

Sun Path or Solar Horizon:

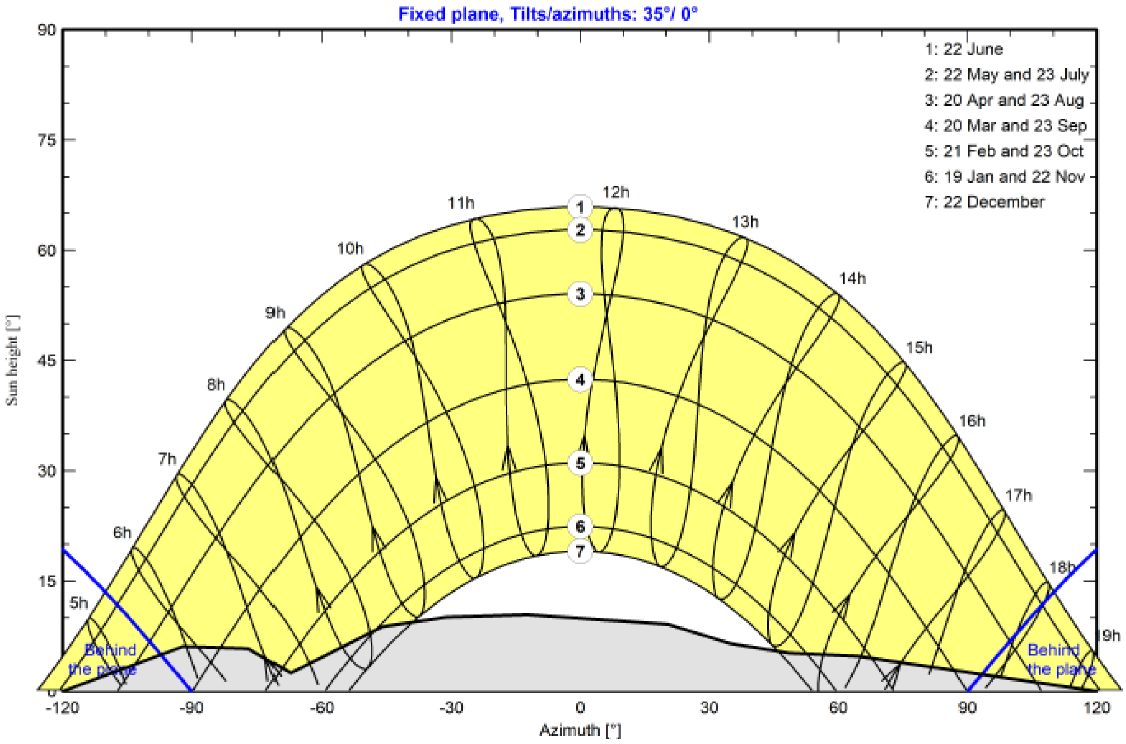


Figure 16: Solar Horizon at Alkotas Utca, Budapest [Own work,Software:PVSyst]

Monthly Normalized Production:

Produced Energy
35114 kWh/year

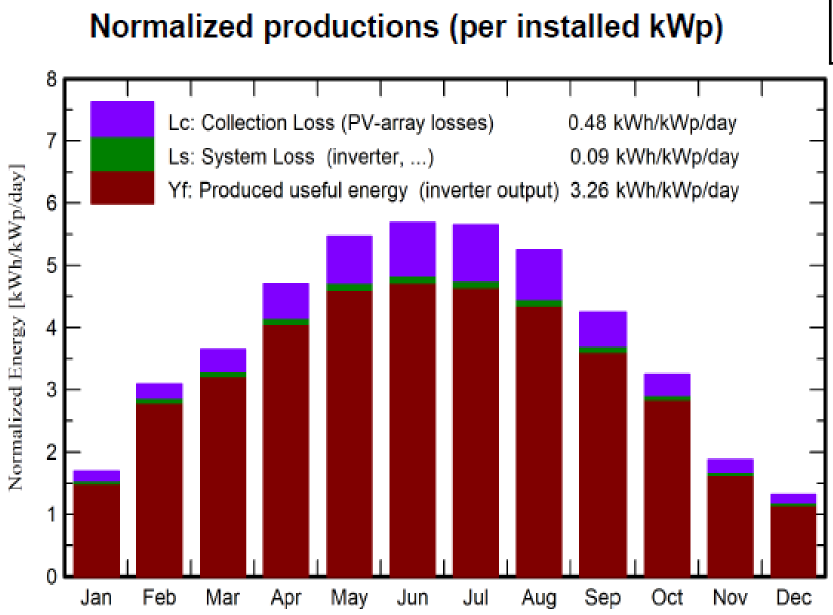


Figure 17: Monthly normalized production for Roof Top Solar EV Charging Station at Alkotas Utca, Budapest [Own work, Software: PVSyst]

Monthly Performance Ratio:

Specific production	1191 kWh/kWp/year
Performance Ratio PR	85.32 %

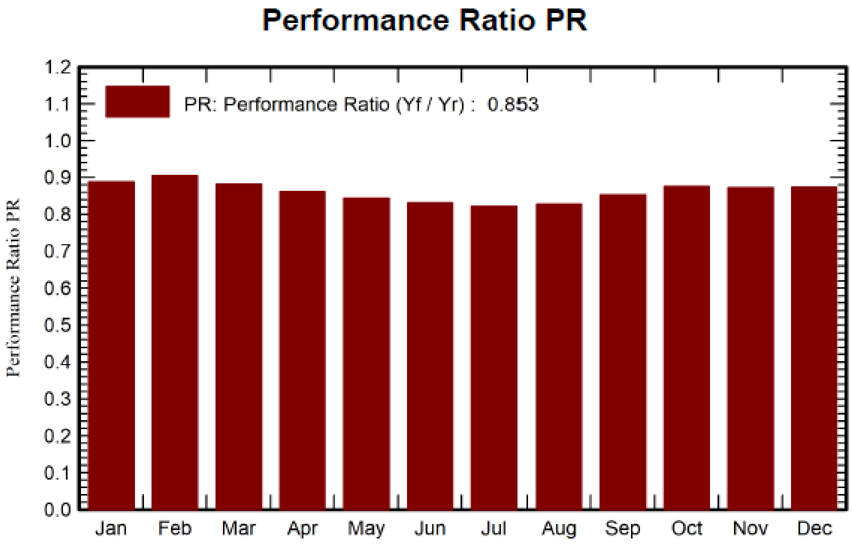


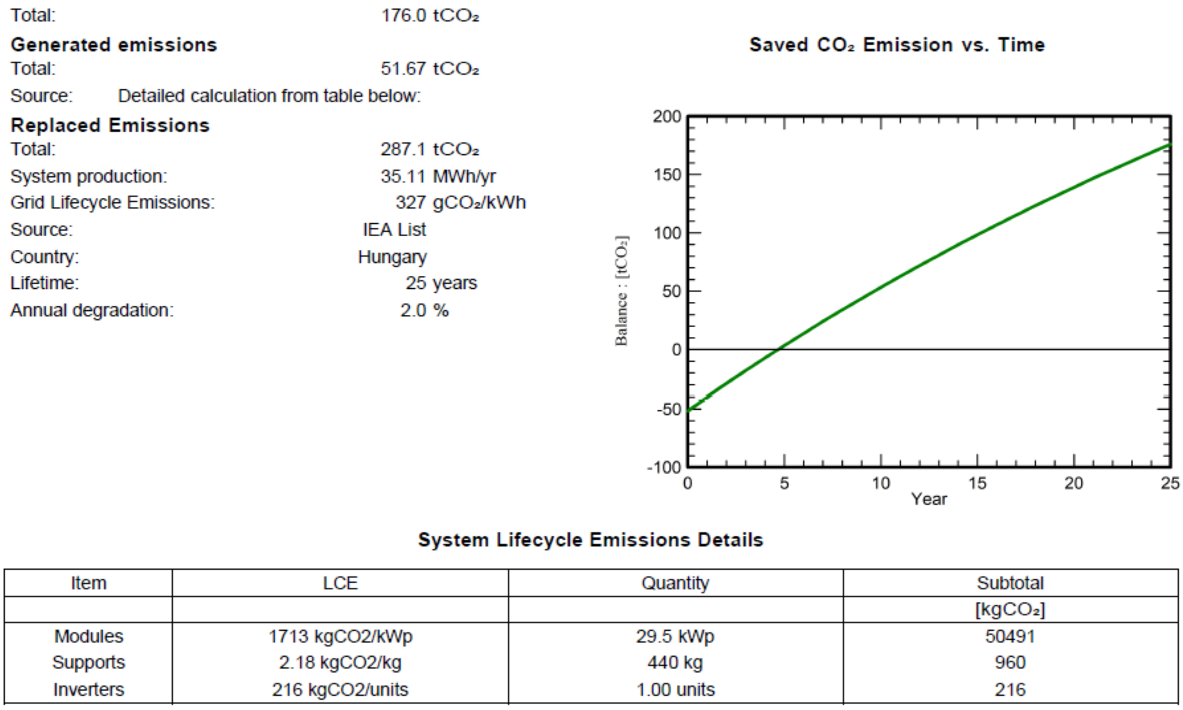
Figure 18: Monthly Performance Ratio for Roof Top Solar EV Charging Station at Alkotas Utca, Budapest [Own work, Software: PVSyst]

Balances and Main Results Month-wise:

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	30.6	18.16	-0.15	52.3	48.5	1411	1368	0.888
February	55.0	24.02	1.55	86.5	83.2	2371	2308	0.905
March	92.3	49.83	6.51	113.1	107.7	3020	2942	0.882
April	129.4	70.69	12.32	141.2	133.9	3680	3588	0.862
May	170.9	78.51	17.17	169.3	160.7	4319	4212	0.844
June	180.1	87.19	20.63	170.6	161.2	4284	4179	0.831
July	180.8	82.27	22.82	175.2	166.2	4350	4245	0.822
August	155.3	80.03	22.44	162.7	154.4	4074	3977	0.829
September	106.0	53.77	16.61	127.3	121.3	3278	3196	0.852
October	70.7	36.72	11.46	100.6	96.3	2668	2599	0.876
November	34.0	19.64	6.16	56.2	52.6	1491	1447	0.873
December	24.5	16.68	0.96	40.9	37.4	1087	1053	0.874
Year	1229.6	617.52	11.60	1396.0	1323.5	36034	35114	0.853

Table 2: Monthly Balances and Results for Roof Top Solar EV Charging Station at Alkotas Utca, Budapest [Own work, Software: PVSyst]

CO2 Emission Balance:



Total: 176.0 tCO_2

Generated emissions

Total: 51.67 tCO_2

Source: Detailed calculation from table below:

Replaced Emissions

Total: 287.1 tCO_2

System production: 35.11 MWh/yr

Grid Lifecycle Emissions: 327 gCO_2/kWh

Source: IEA List

Country: Hungary

Lifetime: 25 years

Annual degradation: 2.0 %

System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	29.5 kWp	50491
Supports	2.18 kgCO2/kg	440 kg	960
Inverters	216 kgCO2/units	1.00 units	216

Figure 19: CO2 Emission Balance Roof Top Solar EV Charging Station at Alkotas Utca, Budapest [Own work, Software: PVSyst]

Loss Diagram:

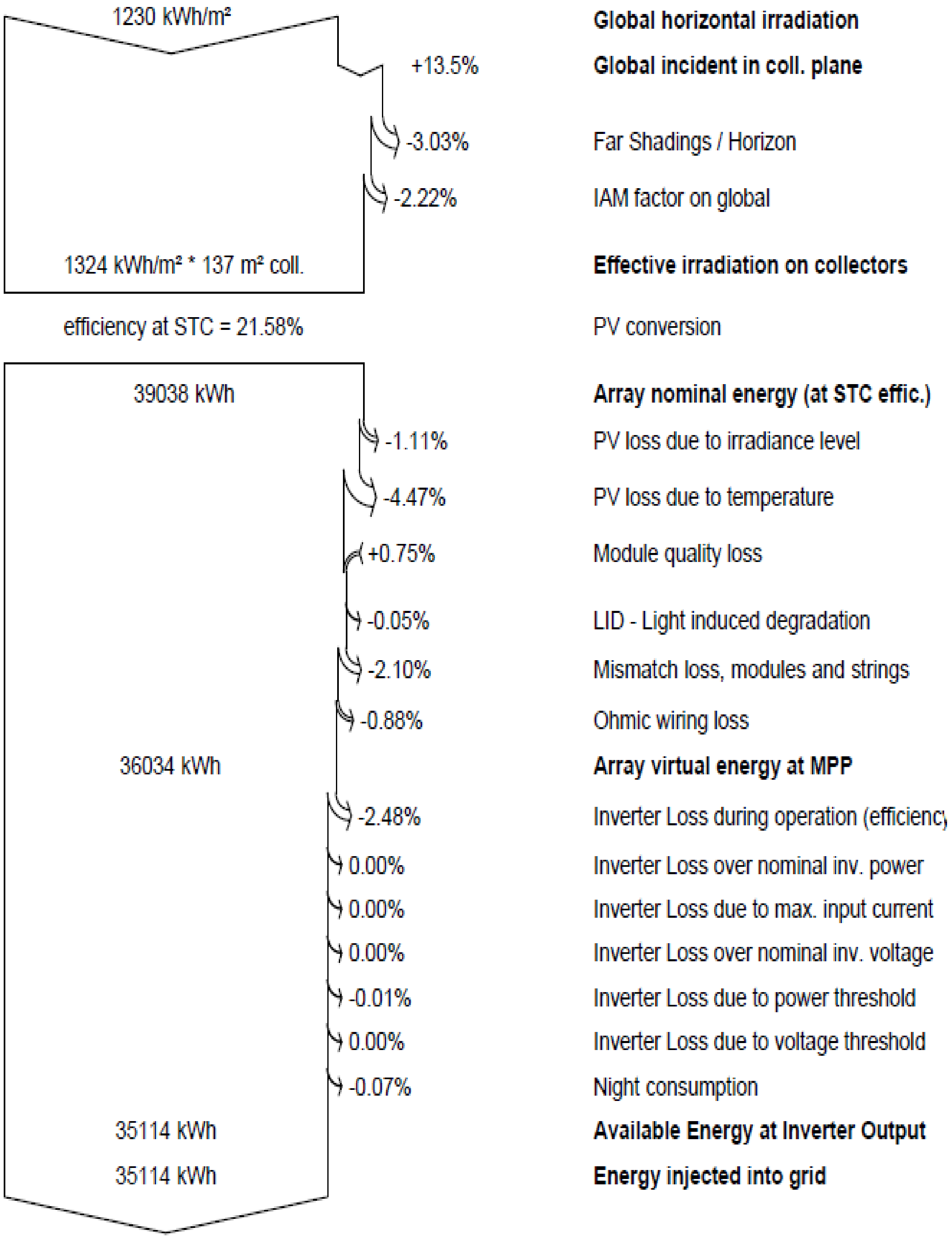


Figure 20: Loss diagram for Roof Top Solar EV Charging Station at Alkotas Utca, Budapest [Own work, Software: PVSyst]

Findings:

The normalized energy production of this Roof Top Solar Photovoltaic (PV) system (Figure 17) throughout the year, measured in kWh per kWp installed capacity per day. Each month's bar is divided into three sections: collection loss (blue) indicating energy lost due to solar panel inefficiencies, system loss (purple) from components like inverters, and the useful energy output (red). From the figure we can see throughout the year, the predominant portion (in red) represents useful energy produced, averaging around 3.26 kWh/kWp/day. Notably, production peaks during May through August. However, two types of losses reduce the total output: Collection Loss (PV-array losses) averaging 0.48 kWh/kWp/day (shown in green) and System Loss due to components like inverters, averaging 0.09 kWh/kWp/day (in purple). These losses are relatively consistent, but their impact is visibly more pronounced during months with lower overall production, like January and December.

The performance ratio (Figure 18) of this system is 85.32%. From Table 2 we can observe Throughout the year, the rooftop solar EV charging station in Alkotás Utca, Budapest, demonstrates evident seasonal fluctuations. The Global Horizontal Irradiance (GlobHor) initiates at 30.6 kWh/m² in January, surging to its apex at 180.8 kWh/m² in July. December witnesses the nadir at 24.5 kWh/m². The Diffuse Horizontal Irradiance (DiffHor) reaches its pinnacle in June, tallying 87.19 kWh/m². Ambient Temperature (T_Amb) is coldest in December, registering 0.96°C, and is warmest in July, scaling up to 22.84°C. The Global Incident Irradiance (GlobInc) and the Global Effective Irradiance (GlobEff) both peak in July, recording 175.2 kWh/m² and 166.2 kWh/m², respectively. The solar array's energy output (EArray) is also at its zenith in July, generating 4,350 kWh. In stark contrast, December produces the minimal solar energy, amounting to just 1,087 kWh.

From Figure 19 we can get the understanding of losses. Upon accounting for the system's losses, it has the potential to generate 35,114 kWh annually, equating to 96 kWh daily. As a result, this roof top PV setup can charge between 1 to 3 electric vehicles daily since the majority of EV models require between 35-60 kWh for a full charge. Over its projected 25-year lifespan, this system could charge an estimated 9,100 to 27,500 electric vehicles. Furthermore, according to Figure 20, this system can offset 176 metric tons of CO2 emissions in 25 years when compared to traditional energy sources.

Case 3: Floating Solar Park on Tisza Dam, Kisköre

Sun Path or Solar Horizon:

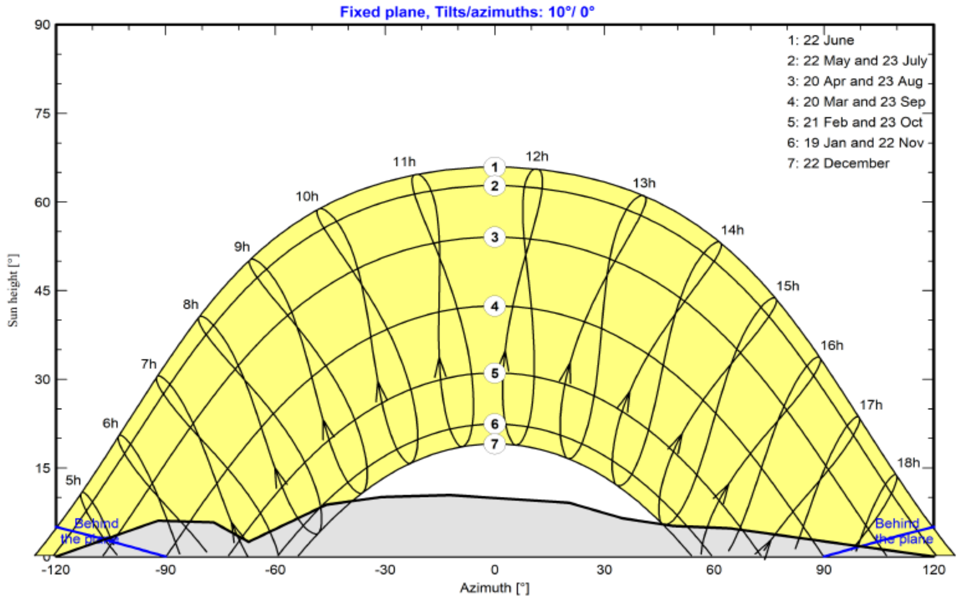
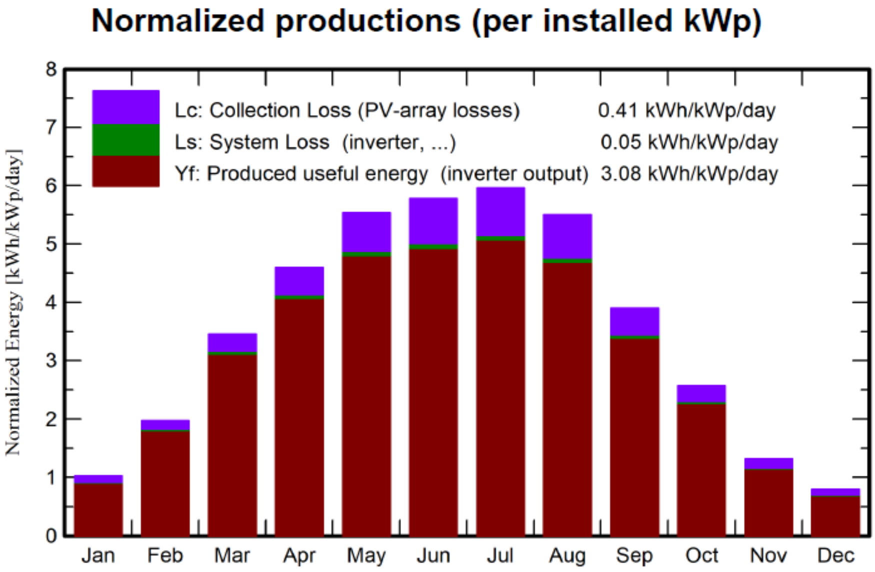


Figure 21: Solar Horizon in Kisköre , Hungary [Own work, Software: PVSyst]

Monthly Normalized Production:

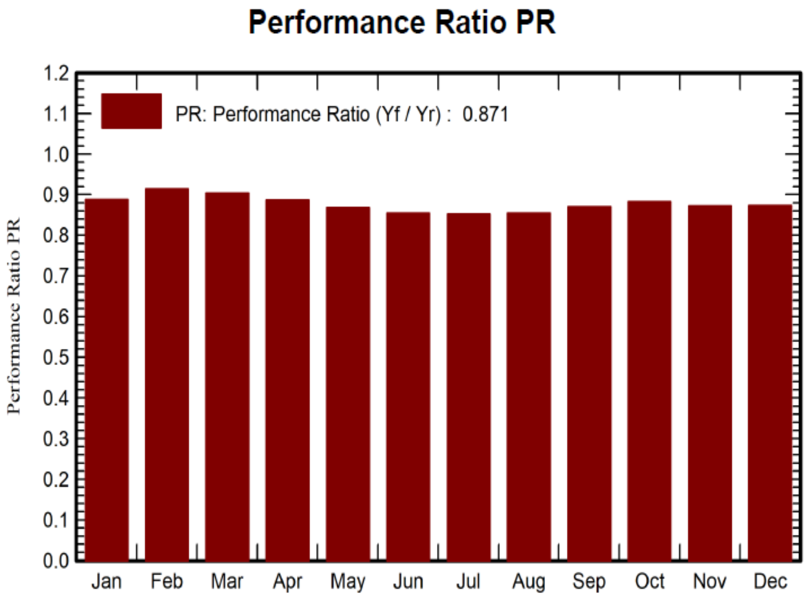


Produced Energy

2851 MWh/year

Figure 22: Monthly normalized production for floating model on Tisza Dam, Kisköre, Hungary [Own work, Software: PVSyst]

Monthly Performance Ratio:



Specific production	1126 kWh/kWp/year
Performance Ratio PR	87.07 %

Figure 23: Monthly Performance Ratio for Floating model on Tisza Dam, Kisköre, Hungary[Own work, Software: PVSyst]

Balances and Main Results Month-wise:

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	26.8	17.96	-0.82	31.8	28.8	72673	71390	0.888
February	47.7	27.37	1.06	55.2	51.4	129848	127769	0.914
March	96.7	48.10	6.53	107.0	100.5	248930	245028	0.904
April	130.9	70.56	12.46	137.9	129.8	314281	309418	0.886
May	168.1	76.27	17.44	171.6	162.2	383206	377152	0.868
June	172.1	80.00	20.86	173.4	163.8	381114	375118	0.854
July	181.4	82.08	23.00	184.7	174.7	404798	398445	0.852
August	162.9	68.25	22.83	170.5	161.5	374599	368782	0.854
September	106.5	48.53	16.88	117.0	110.1	261954	257906	0.870
October	69.8	38.32	11.61	79.8	74.3	181111	178346	0.883
November	33.1	20.46	6.17	39.5	35.9	88727	87250	0.872
December	20.8	15.22	0.55	24.6	22.1	55435	54379	0.874
Year	1216.6	593.13	11.61	1293.0	1215.1	2896674	2850983	0.871

Table 3: Monthly Balances and Results for Floating model on Tisza Dam, Kisköre, Hungary [Own work, Software: PVSyst]

Loss Diagram:

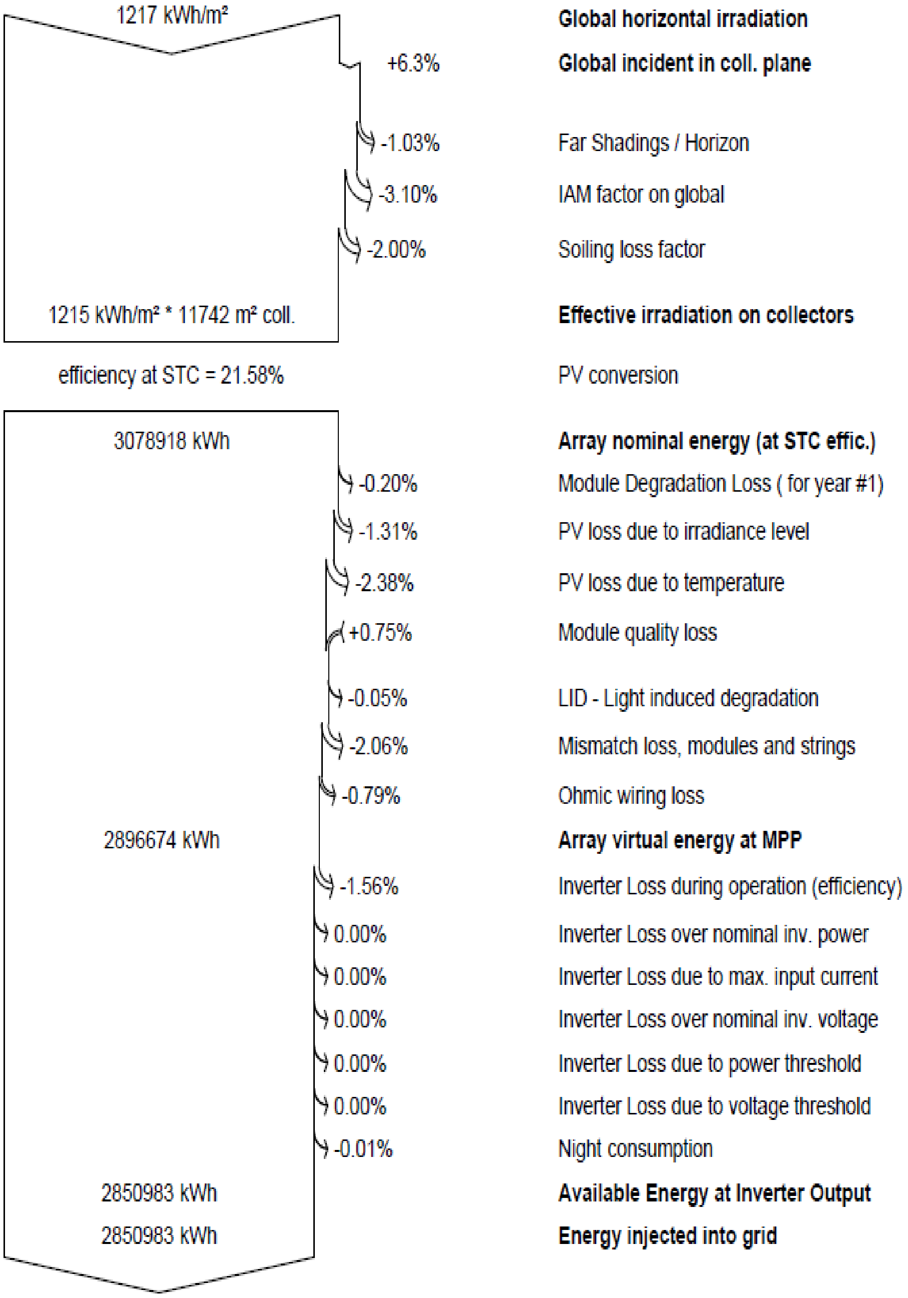
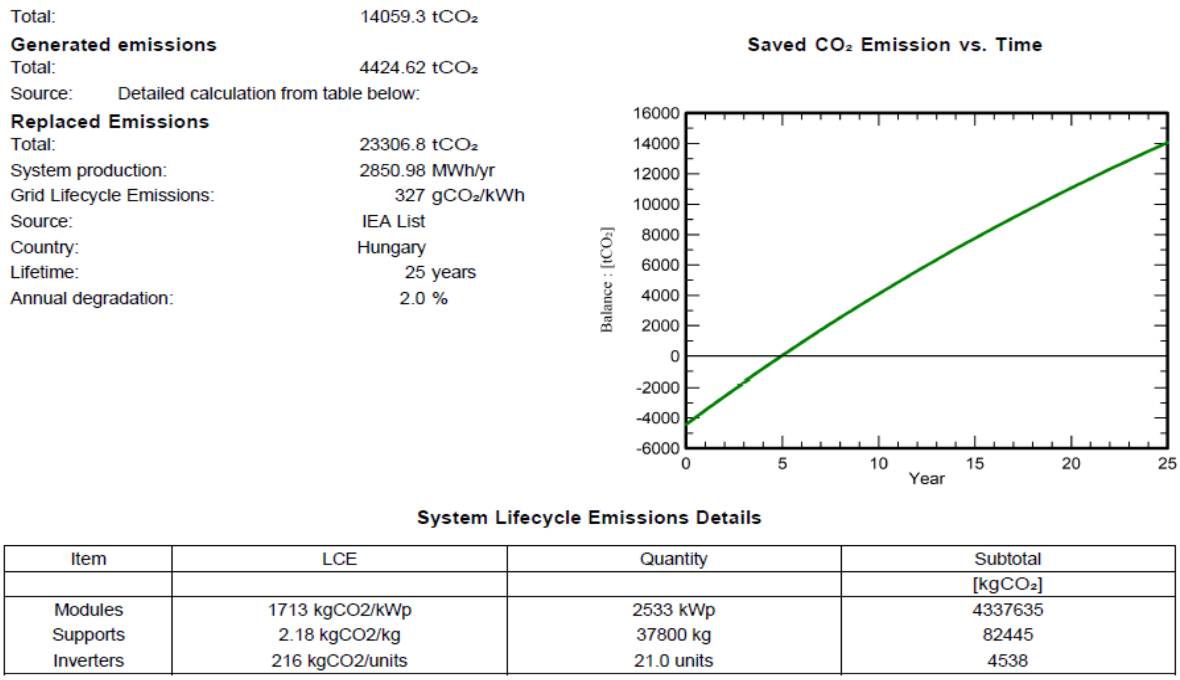


Figure 24: Loss diagram for Floating model on Tisza Dam, Kisköre, Hungary[Own work, Software: PVSyst]

CO2 Emission Balance:



Total:	14059.3 tCO_2

Generated emissions

Total:	4424.62 tCO_2

Source: Detailed calculation from table below:

Replaced Emissions

Total:	23306.8 tCO_2
System production:	2850.98 MWh/yr
Grid Lifecycle Emissions:	327 gCO_2/kWh
Source:	IEA List
Country:	Hungary
Lifetime:	25 years
Annual degradation:	2.0 %

System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	2533 kWp	4337635
Supports	2.18 kgCO2/kg	37800 kg	82445
Inverters	216 kgCO2/units	21.0 units	4538

Figure 25: CO2 Emission Balance for Floating model on Tisza Dam, Kisköre, Hungary[Own work, Software: PVSyst]

Findings:

The normalized energy production of this Ground Mounted Solar Photovoltaic (PV) system (Figure 22) throughout the year, measured in kWh per kWp installed capacity per day. Each month's bar is divided into three sections: collection loss (blue) indicating energy lost due to solar panel inefficiencies, system loss (purple) from components like inverters, and the useful energy output (red). On average, the system experiences 0.41 kWh/kWp/day in collection losses, 0.05 kWh/kWp/day in system losses, and produces 3.08 kWh/kWp/day of useful energy. The Performance ratio (Figure 13) of this system is 87.07 %.

From Table 3 we get, the Global Horizontal Irradiance (GlobHor) starts at 26.8 kWh/m² in January and peaks at 181.4 kWh/m² in July, reflecting maximum sunlight during summer. Conversely, December has the lowest GlobHor value at 20.8 kWh/m². The Diffuse Horizontal Irradiance (DiffHor) peaks in July at 82.08 kWh/m². The Global Incident Irradiance (GlobInc) and Global Effective Irradiance (GlobEff) reach their maxima in July, with values of 184.7 kWh/m² and 174.7 kWh/m², respectively. The energy output from the solar array (EArray) also peaks in July at 404.8 MWh, emphasizing the strong solar activity during the summer. On the other hand, December exhibits the least solar energy output with only 55.43 MWh.

From Figure 24 we can get the understanding of losses. After the deduction of losses this system is capable to produce 2,851 MWh/year (237.6 MWh/month). The Tisza Dam, located in Kisköre within Heves County. From 2000 to 2022, the average monthly electricity consumption in Heves County was recorded at 194.75 kWh. This 2.5 MWp Floating Photovoltaic (FPV) park, capable of producing approximately 2,851 MWh annually. From 2000 to 2022, the Tisza Dam in Kisköre, Heves County, witnessed an average monthly electricity consumption of 194.75 kWh. With the estimated annual energy output of this solar park, nearly 1,220 households within Heves County could be fully powered. Furthermore, according to Figure 25, this system can offset 14059.3 metric tons of CO2 emissions in 25 years when compared to traditional energy sources.

3.2.4 Economical Aanalysis

In this section economic analysis has been done. Economic Analysis is based on Cost Analysis and Financial Analysis. Cost Analysis is Divided into two portion- Imported Portion and Local Portion. Per kWp energy production cost is determined by summation of both portions. From Financial model mainly we get

Payback Period:

$$PP = \frac{Investment\ Amount}{Annual\ Profit}$$

Rate of Interest

$$ROI = \frac{Net\ Income\ (income - cost)}{Project\ Cost} \times 100$$

Net Present Value (NPV):

$$NPV = \sum \frac{CFBF_t}{(1+r)^t} - CAPEX_{(\$)}$$

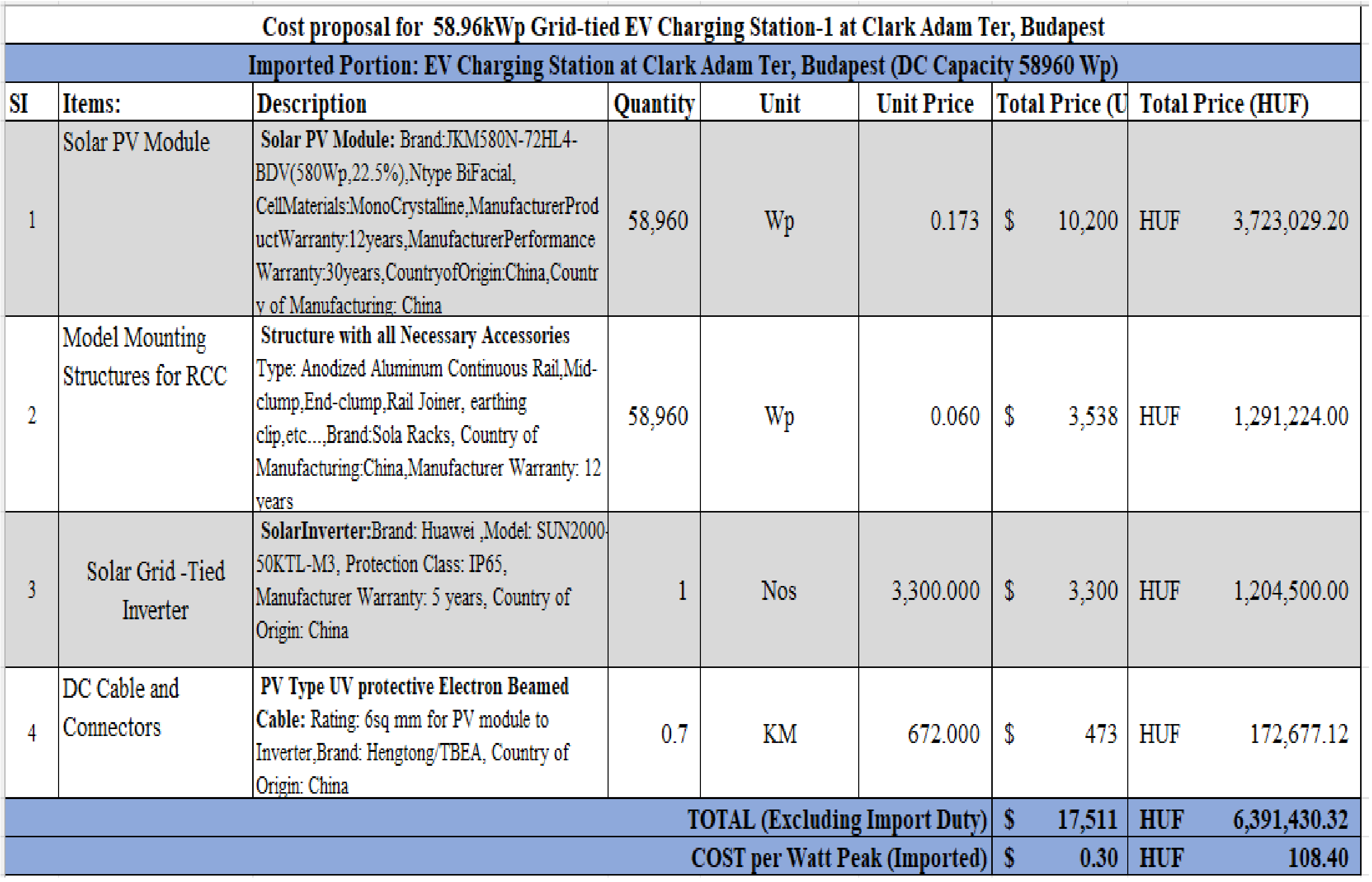
[**CapEx ($)** = Equipment Costs + Installation Costs + Permitting Costs + Engineering Costs + Land Costs + Other Initial Costs, **CFBF ($)** = CFO - CapEx]

Average unit cost or levelized cost of electricity/kWh

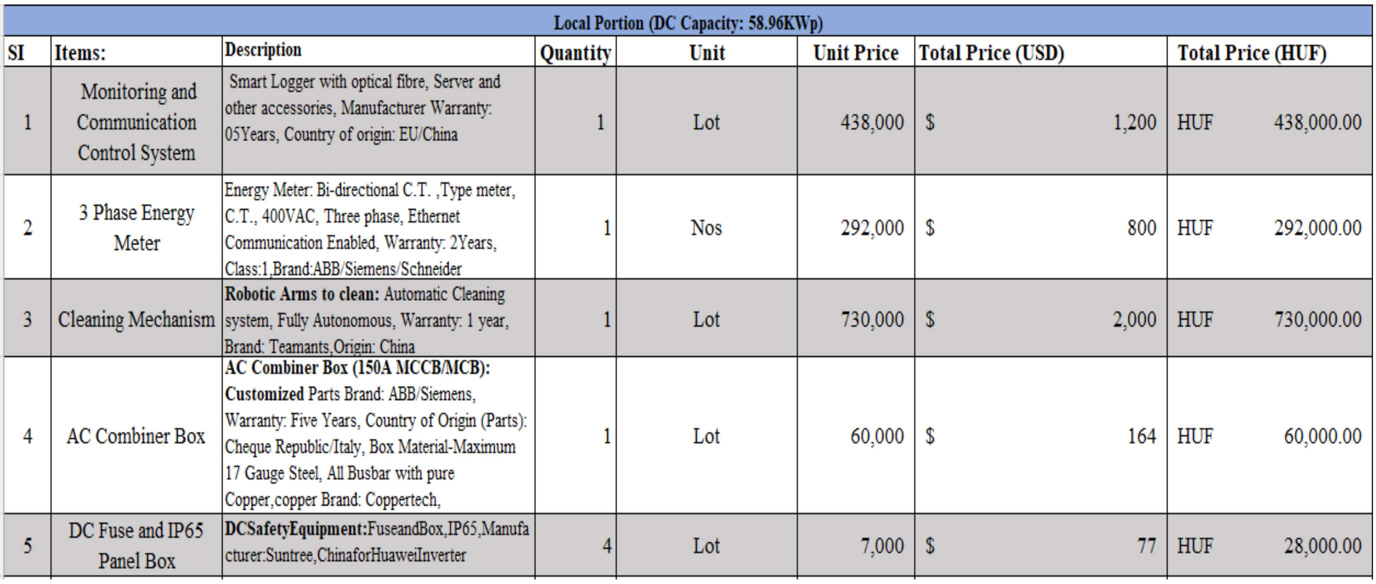
$$LCOE = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

Case 1: Ground-Mounted Solar EV Charging Station at Clark Adam Ter, Budapest

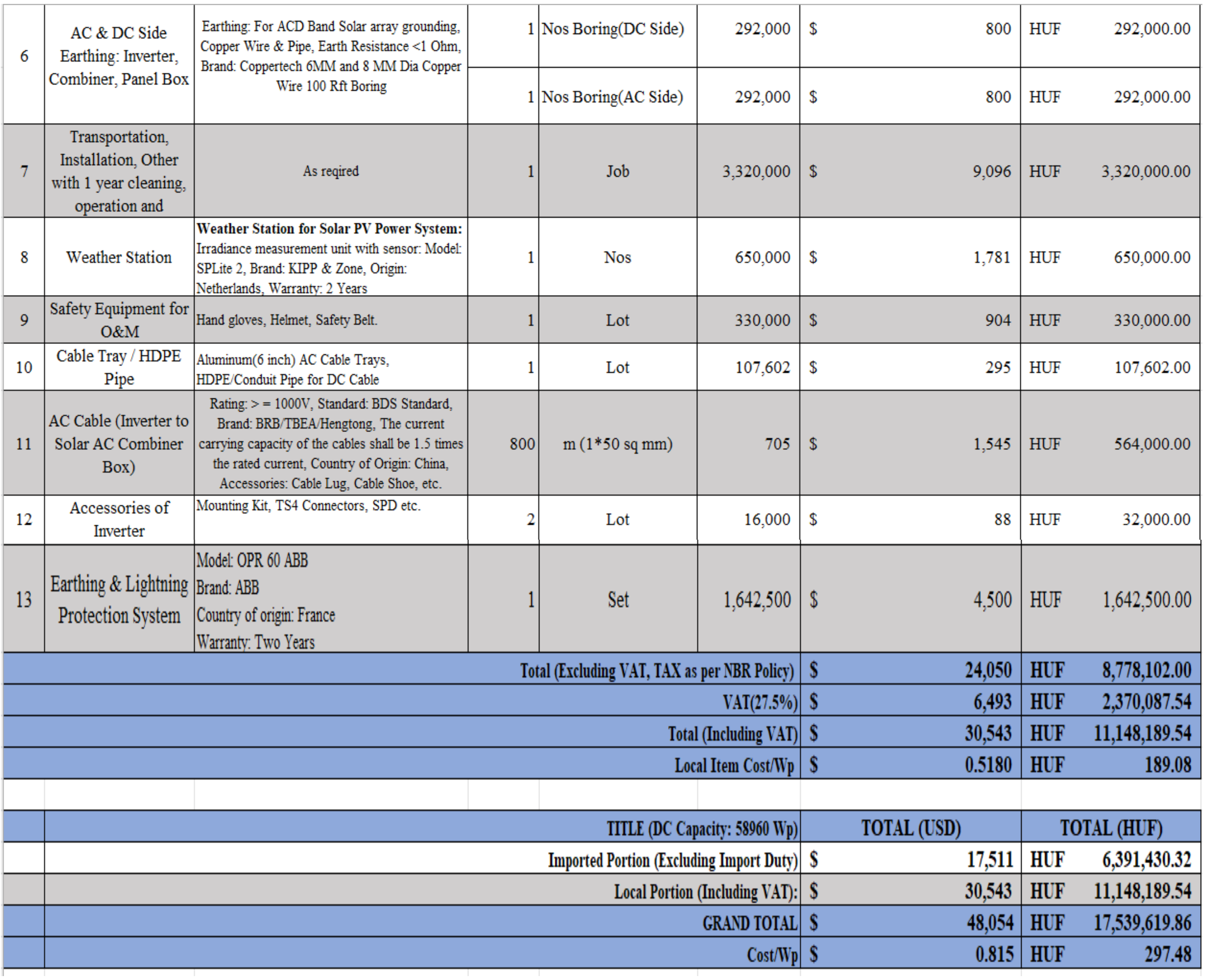
Cost Analysis:



Cost proposal for 58.96kWp Grid-tied EV Charging Station-1 at Clark Adam Ter, Budapest							
Imported Portion: EV Charging Station at Clark Adam Ter, Budapest (DC Capacity 58960 Wp)							
SI	**Items:**	**Description**	**Quantity**	**Unit**	**Unit Price**	**Total Price (U**	**Total Price (HUF)**
1	Solar PV Module	**Solar PV Module:** Brand:JKM580N-72HL4-BDV(580Wp,22.5%),Ntype BiFacial, CellMaterials:MonoCrystalline,ManufacturerProductWarranty:12years,ManufacturerPerformance Warranty:30years,CountryofOrigin:China,Country of Manufacturing: China	58,960	Wp	0.173	$ 10,200	HUF 3,723,029.20
2	Model Mounting Structures for RCC	**Structure with all Necessary Accessories** Type: Anodized Aluminum Continuous Rail,Mid-clump,End-clump,Rail Joiner, earthing clip,etc...,Brand:Sola Racks, Country of Manufacturing:China,Manufacturer Warranty: 12 years	58,960	Wp	0.060	$ 3,538	HUF 1,291,224.00
3	Solar Grid -Tied Inverter	**SolarInverter:**Brand: Huawei ,Model: SUN2000-50KTL-M3, Protection Class: IP65, Manufacturer Warranty: 5 years, Country of Origin: China	1	Nos	3,300.000	$ 3,300	HUF 1,204,500.00
4	DC Cable and Connectors	**PV Type UV protective Electron Beamed Cable:** Rating: 6sq mm for PV module to Inverter,Brand: Hengtong/TBEA, Country of Origin: China	0.7	KM	672.000	$ 473	HUF 172,677.12
					TOTAL (Excluding Import Duty)	**$ 17,511**	**HUF 6,391,430.32**
					COST per Watt Peak (Imported)	**$ 0.30**	**HUF 108.40**



Local Portion (DC Capacity: 58.96KWp)							
SI	**Items:**	**Description**	**Quantity**	**Unit**	**Unit Price**	**Total Price (USD)**	**Total Price (HUF)**
1	Monitoring and Communication Control System	Smart Logger with optical fibre, Server and other accessories, Manufacturer Warranty: 05Years, Country of origin: EU/China	1	Lot	438,000	$ 1,200	HUF 438,000.00
2	3 Phase Energy Meter	Energy Meter: Bi-directional C.T. ,Type meter, C.T., 400VAC, Three phase, Ethernet Communication Enabled, Warranty: 2Years, Class:1,Brand:ABB/Siemens/Schneider	1	Nos	292,000	$ 800	HUF 292,000.00
3	Cleaning Mechanism	**Robotic Arms to clean:** Automatic Cleaning system, Fully Autonomous, Warranty: 1 year, Brand: Teamants,Origin: China	1	Lot	730,000	$ 2,000	HUF 730,000.00
4	AC Combiner Box	**AC Combiner Box (150A MCCB/MCB): Customized** Parts Brand: ABB/Siemens, Warranty: Five Years, Country of Origin (Parts): Cheque Republic/Italy, Box Material-Maximum 17 Gauge Steel, All Busbar with pure Copper,copper Brand: Coppertech,	1	Lot	60,000	$ 164	HUF 60,000.00
5	DC Fuse and IP65 Panel Box	**DCSafetyEquipment:**FuseandBox,IP65,Manufacturer:Suntree,ChinaforHuaweiInverter	4	Lot	7,000	$ 77	HUF 28,000.00



6	AC & DC Side Earthing: Inverter, Combiner, Panel Box	Earthing: For ACD Band Solar array grounding, Copper Wire & Pipe, Earth Resistance <1 Ohm, Brand: Coppertech 6MM and 8 MM Dia Copper Wire 100 Rft Boring	1	Nos Boring(DC Side)	292,000	$	800	HUF	292,000.00
			1	Nos Boring(AC Side)	292,000	$	800	HUF	292,000.00
7	Transportation, Installation, Other with 1 year cleaning, operation and	As reqired	1	Job	3,320,000	$	9,096	HUF	3,320,000.00
8	Weather Station	**Weather Station for Solar PV Power System:** Irradiance measurement unit with sensor: Model: SPLite 2, Brand: KIPP & Zone, Origin: Netherlands, Warranty: 2 Years	1	Nos	650,000	$	1,781	HUF	650,000.00
9	Safety Equipment for O&M	Hand gloves, Helmet, Safety Belt.	1	Lot	330,000	$	904	HUF	330,000.00
10	Cable Tray / HDPE Pipe	Aluminum(6 inch) AC Cable Trays, HDPE/Conduit Pipe for DC Cable	1	Lot	107,602	$	295	HUF	107,602.00
11	AC Cable (Inverter to Solar AC Combiner Box)	Rating: > = 1000V, Standard: BDS Standard, Brand: BRB/TBEA/Hengtong, The current carrying capacity of the cables shall be 1.5 times the rated current, Country of Origin: China, Accessories: Cable Lug, Cable Shoe, etc.	800	m (1*50 sq mm)	705	$	1,545	HUF	564,000.00
12	Accessories of Inverter	Mounting Kit, TS4 Connectors, SPD etc.	2	Lot	16,000	$	88	HUF	32,000.00
13	Earthing & Lightning Protection System	Model: OPR 60 ABB Brand: ABB Country of origin: France Warranty: Two Years	1	Set	1,642,500	$	4,500	HUF	1,642,500.00
Total (Excluding VAT, TAX as per NBR Policy)						**$**	**24,050**	**HUF**	**8,778,102.00**
VAT(27.5%)						**$**	**6,493**	**HUF**	**2,370,087.54**
Total (Including VAT)						**$**	**30,543**	**HUF**	**11,148,189.54**
Local Item Cost/Wp						**$**	**0.5180**	**HUF**	**189.08**
	TITLE (DC Capacity: 58960 Wp)					**TOTAL (USD)**		**TOTAL (HUF)**	
	Imported Portion (Excluding Import Duty)					**$**	**17,511**	**HUF**	**6,391,430.32**
	Local Portion (Including VAT):					**$**	**30,543**	**HUF**	**11,148,189.54**
	GRAND TOTAL					**$**	**48,054**	**HUF**	**17,539,619.86**
	Cost/Wp					**$**	**0.815**	**HUF**	**297.48**

Table 4: Cost proposal for 58.96kWp Grid-tied EV Charging Station-1 at Clark Adam Ter, Budapest [Own work, Software: Excel]

Analysis of Cost per Unit Capacity for Ground-Mounted Solar EV Charging Station at Clark Adam Ter, Budapest:

This aims to provide an analysis of the financial aspects of a proposed Electric Vehicle (EV) Charging Station, delineating the cost associated with each unit of installed capacity.

Project Specifications: The proposed EV Charging Station is projected to have an installed capacity of 58.9 kWp58.9kWp.

Financial Overview: The total financial outlay proposed for this project is as follows:

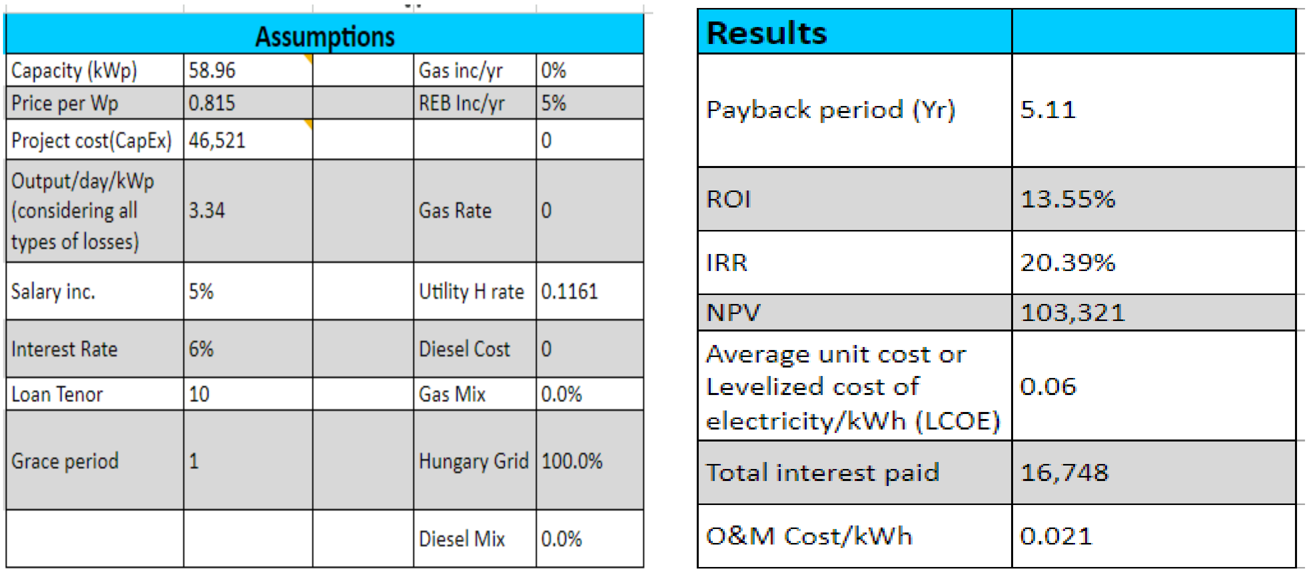
- Total Cost: $48,054 USD
- Equivalent Cost in HUF: 17,539,619.86 HUF (considering an exchange rate of 1 USD = 365 HUF)

Cost Analysis: To discern the cost efficiency of the installation, we calculate the cost per watt-peak (Wp) as follows:

1. **Cost per Wp in USD:** Total Cost (USD)/Total Capacity (kWp)
   48,054 USD/58,900 Wp
   ≈0.815 USD/Wp
2. **Cost per Wp in HUF:** Cost per Wp (USD)×Exchange rate (HUF/USD)
   0.815 USD/Wp×365 HUF/USD
   ≈297.48 HUF/Wp

Tax Consideration: It is imperative to note that the aforementioned cost includes a tax of 27.5%.

Financial Model:



Assumptions				
Capacity (kWp)	58.96		Gas inc/yr	0%
Price per Wp	0.815		REB Inc/yr	5%
Project cost(CapEx)	46,521			0
Output/day/kWp (considering all types of losses)	3.34		Gas Rate	0
Salary inc.	5%		Utility H rate	0.1161
Interest Rate	6%		Diesel Cost	0
Loan Tenor	10		Gas Mix	0.0%
Grace period	1		Hungary Grid	100.0%
			Diesel Mix	0.0%

Results	
Payback period (Yr)	5.11
ROI	13.55%
IRR	20.39%
NPV	103,321
Average unit cost or Levelized cost of electricity/kWh (LCOE)	0.06
Total interest paid	16,748
O&M Cost/kWh	0.021

Table 5: Financial Model for 58.96kWp Grid-tied EV Charging Station-1 at Clark Adam Ter, Budapest [Own work, Software: Excel]

Analysis of Financial Model for Ground-Mounted Solar EV Charging Station at Clark Adam Ter, Budapest:

The table 5 summarize the financial results from an analysis of a project, presumably related to the EV Charging Station mentioned previously or another energy project. Detailed calculation has been included in the Appendix A. Here is an interpretation of the results provided:

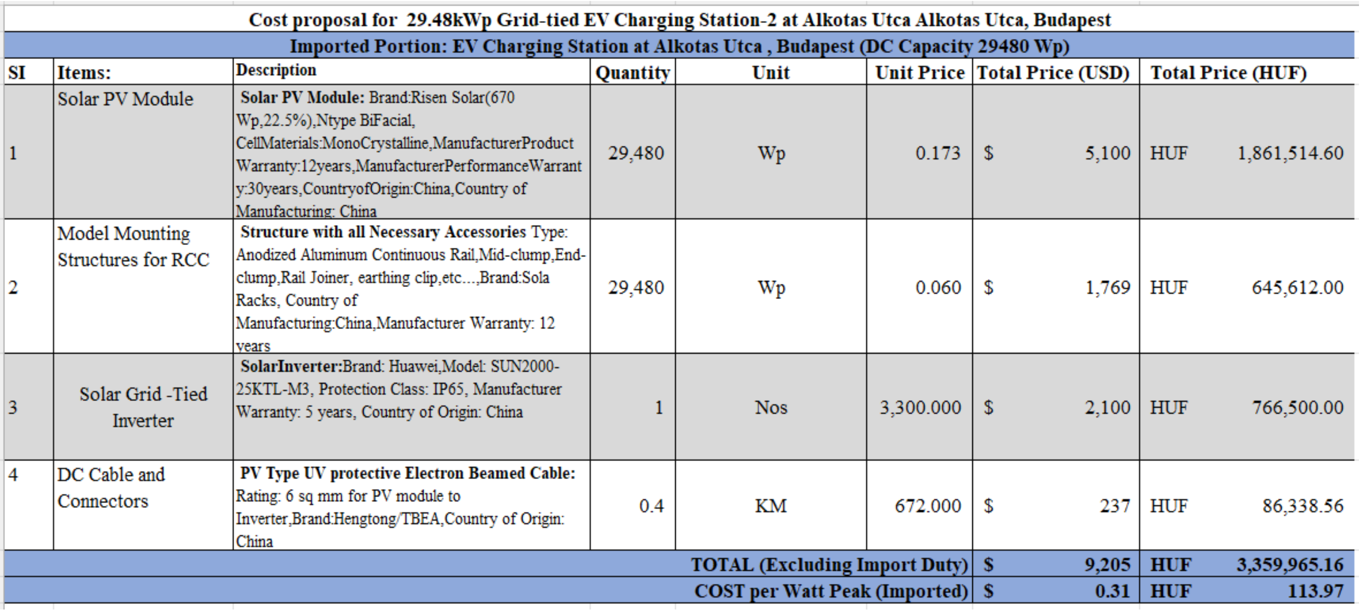
1. **Payback Period:** The project will take 5.11 years to recoup the initial investment costs. This is a relatively short payback period, which can be considered favorable in most investment scenarios.
2. **Return on Investment (ROI):** The ROI of 13.55% indicates a positive profitability outlook. This percentage shows what the return is on each dollar invested, which in this case is a 13.55% gain.

3. **Internal Rate of Return (IRR):** With an IRR of 20.39%, the project exceeds the usual benchmark for investment attractiveness. This rate is the interest rate at which the net present value of the costs of the investment equals the net present value of the benefits, suggesting good potential for profitability.
4. **Net Present Value (NPV):** The NPV of the project is 103,321. A positive NPV indicates that the projected earnings (in present dollars) exceed the anticipated costs (also in present dollars), making it a financially viable project.
5. **Levelized Cost of Electricity (LCOE):** The average unit cost or LCOE is $0.06 per kWh, which represents the per-unit cost (in this case, per kWh) of building and operating a generating plant over an assumed financial life and duty cycle.
6. **Total Interest Paid:** The total interest paid over the life of the project is 16,748, which could be related to the financing of the project. This figure is important for understanding the cost of the loan or financial leverage used in the project.
7. **Operations and Maintenance (O&M) Cost:** This is the cost of running the charging station on a per kWh basis, at $0.021. It is a critical factor for long-term financial planning as it affects the net cash flow from the project.

These financial indicators suggest that the project is economically feasible with a solid return and reasonable operational costs. The analysis seems comprehensive and reflects a well-planned project that takes into account the main financial metrics necessary for thorough evaluation.

Case 2: Roof Top Model Solar EV Charging Station at Alkotas Utca, Budapest

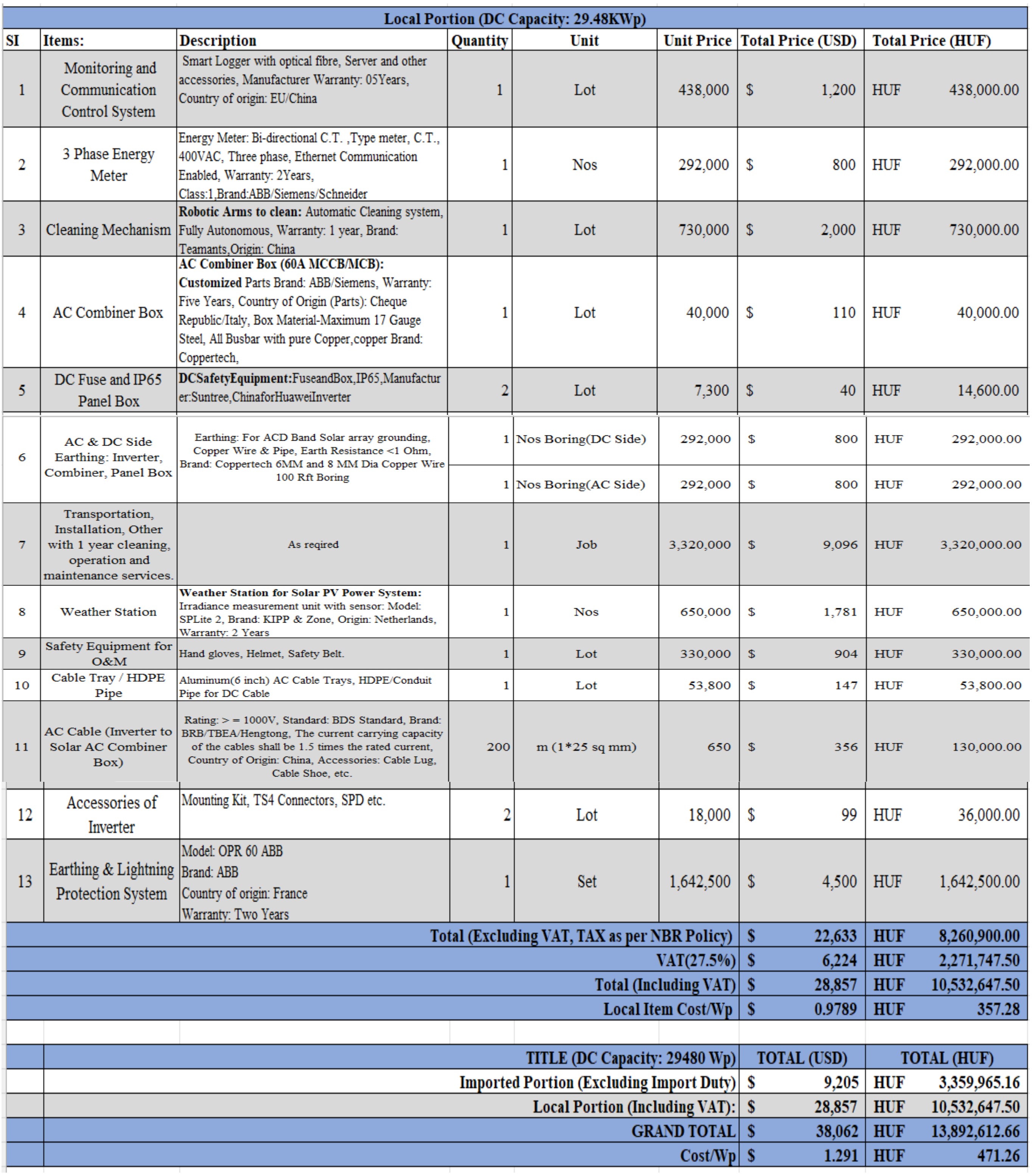
Cost Analysis:



Cost proposal for 29.48kWp Grid-tied EV Charging Station-2 at Alkotas Utca Alkotas Utca, Budapest

Imported Portion: EV Charging Station at Alkotas Utca , Budapest (DC Capacity 29480 Wp)

SI	Items:	Description	Quantity	Unit	Unit Price	Total Price (USD)	Total Price (HUF)
1	Solar PV Module	**Solar PV Module:** Brand:Risen Solar(670 Wp,22.5%),Ntype BiFacial, CellMaterials:MonoCrystalline,ManufacturerProduct Warranty:12years,ManufacturerPerformanceWarranty:30years,CountryofOrigin:China,Country of Manufacturing: China	29,480	Wp	0.173	$ 5,100	HUF 1,861,514.60
2	Model Mounting Structures for RCC	**Structure with all Necessary Accessories** Type: Anodized Aluminum Continuous Rail,Mid-clump,End-clump,Rail Joiner, earthing clip,etc...,Brand:Sola Racks, Country of Manufacturing:China,Manufacturer Warranty: 12 years	29,480	Wp	0.060	$ 1,769	HUF 645,612.00
3	Solar Grid -Tied Inverter	**SolarInverter:**Brand: Huawei,Model: SUN2000-25KTL-M3, Protection Class: IP65, Manufacturer Warranty: 5 years, Country of Origin: China	1	Nos	3,300.000	$ 2,100	HUF 766,500.00
4	DC Cable and Connectors	**PV Type UV protective Electron Beamed Cable:** Rating: 6 sq mm for PV module to Inverter,Brand:Hengtong/TBEA,Country of Origin: China	0.4	KM	672.000	$ 237	HUF 86,338.56
					TOTAL (Excluding Import Duty)	**$ 9,205**	**HUF 3,359,965.16**
					COST per Watt Peak (Imported)	**$ 0.31**	**HUF 113.97**



Local Portion (DC Capacity: 29.48KWp)							
SI	Items:	Description	Quantity	Unit	Unit Price	Total Price (USD)	Total Price (HUF)
1	Monitoring and Communication Control System	Smart Logger with optical fibre, Server and other accessories, Manufacturer Warranty: 05Years, Country of origin: EU/China	1	Lot	438,000	$ 1,200	HUF 438,000.00
2	3 Phase Energy Meter	Energy Meter: Bi-directional C.T. ,Type meter, C.T., 400VAC, Three phase, Ethernet Communication Enabled, Warranty: 2Years, Class:1,Brand:ABB/Siemens/Schneider	1	Nos	292,000	$ 800	HUF 292,000.00
3	Cleaning Mechanism	**Robotic Arms to clean:** Automatic Cleaning system, Fully Autonomous, Warranty: 1 year, Brand: Teamants,Origin: China	1	Lot	730,000	$ 2,000	HUF 730,000.00
4	AC Combiner Box	**AC Combiner Box (60A MCCB/MCB): Customized** Parts Brand: ABB/Siemens, Warranty: Five Years, Country of Origin (Parts): Cheque Republic/Italy, Box Material-Maximum 17 Gauge Steel, All Busbar with pure Copper,copper Brand: Coppertech,	1	Lot	40,000	$ 110	HUF 40,000.00
5	DC Fuse and IP65 Panel Box	**DCSafetyEquipment:**FuseandBox,IP65,Manufacturer:Suntree,ChinaforHuaweiInverter	2	Lot	7,300	$ 40	HUF 14,600.00
6	AC & DC Side Earthing: Inverter, Combiner, Panel Box	Earthing: For ACD Band Solar array grounding, Copper Wire & Pipe, Earth Resistance <1 Ohm, Brand: Coppertech 6MM and 8 MM Dia Copper Wire 100 Rft Boring	1	Nos Boring(DC Side)	292,000	$ 800	HUF 292,000.00
			1	Nos Boring(AC Side)	292,000	$ 800	HUF 292,000.00
7	Transportation, Installation, Other with 1 year cleaning, operation and maintenance services.	As reqired	1	Job	3,320,000	$ 9,096	HUF 3,320,000.00
8	Weather Station	**Weather Station for Solar PV Power System:** Irradiance measurement unit with sensor: Model: SPLite 2, Brand: KIPP & Zone, Origin: Netherlands, Warranty: 2 Years	1	Nos	650,000	$ 1,781	HUF 650,000.00
9	Safety Equipment for O&M	Hand gloves, Helmet, Safety Belt.	1	Lot	330,000	$ 904	HUF 330,000.00
10	Cable Tray / HDPE Pipe	Aluminum(6 inch) AC Cable Trays, HDPE/Conduit Pipe for DC Cable	1	Lot	53,800	$ 147	HUF 53,800.00
11	AC Cable (Inverter to Solar AC Combiner Box)	Rating: > = 1000V, Standard: BDS Standard, Brand: BRB/TBEA/Hengtong, The current carrying capacity of the cables shall be 1.5 times the rated current, Country of Origin: China, Accessories: Cable Lug, Cable Shoe, etc.	200	m (1*25 sq mm)	650	$ 356	HUF 130,000.00
12	Accessories of Inverter	Mounting Kit, TS4 Connectors, SPD etc.	2	Lot	18,000	$ 99	HUF 36,000.00
13	Earthing & Lightning Protection System	Model: OPR 60 ABB Brand: ABB Country of origin: France Warranty: Two Years	1	Set	1,642,500	$ 4,500	HUF 1,642,500.00
Total (Excluding VAT, TAX as per NBR Policy)						**$ 22,633**	**HUF 8,260,900.00**
VAT(27.5%)						**$ 6,224**	**HUF 2,271,747.50**
Total (Including VAT)						**$ 28,857**	**HUF 10,532,647.50**
Local Item Cost/Wp						**$ 0.9789**	**HUF 357.28**
	TITLE (DC Capacity: 29480 Wp)					**TOTAL (USD)**	**TOTAL (HUF)**
	Imported Portion (Excluding Import Duty)					**$ 9,205**	**HUF 3,359,965.16**
	Local Portion (Including VAT):					**$ 28,857**	**HUF 10,532,647.50**
	GRAND TOTAL					**$ 38,062**	**HUF 13,892,612.66**
	Cost/Wp					**$ 1.291**	**HUF 471.26**

Table 6: Cost Proposal for Roof Top Model Solar EV Charging Station-2 at Alkotas Utca, Budapest [Own work, Software: Excel]

Analysis of Cost per Unit Capacity for Roof Top Model Solar EV Charging Station-2 at Alkotas Utca, Budapest:

This aims to provide an analysis of the financial aspects of a proposed Electric Vehicle (EV) Charging Station, delineating the cost associated with each unit of installed capacity.

Project Specifications: The proposed EV Charging Station is projected to have an installed capacity of 29.48 kWp.

Financial Overview: The total financial outlay proposed for this project is as follows:

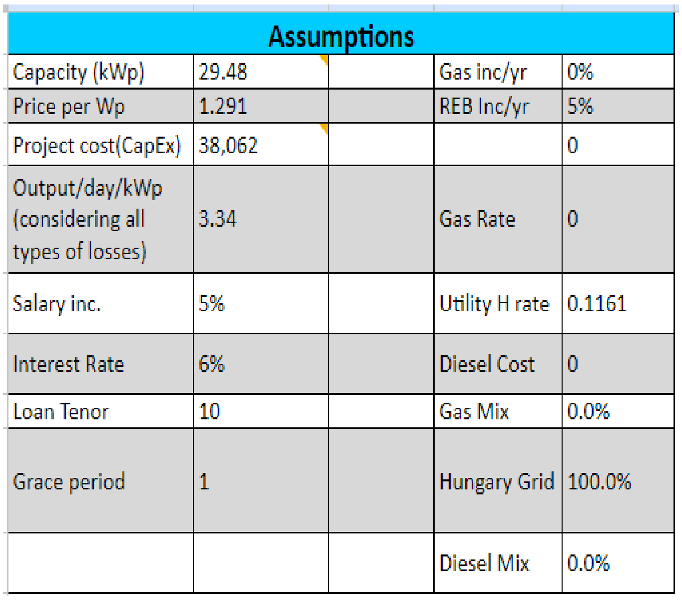
- Total Cost: $38,062 USD
- Equivalent Cost in HUF: 13,892,612.66 HUF (considering an exchange rate of 1 USD = 365 HUF)

Cost Analysis: To discern the cost efficiency of the installation, we calculate the cost per watt-peak (Wp) as follows:

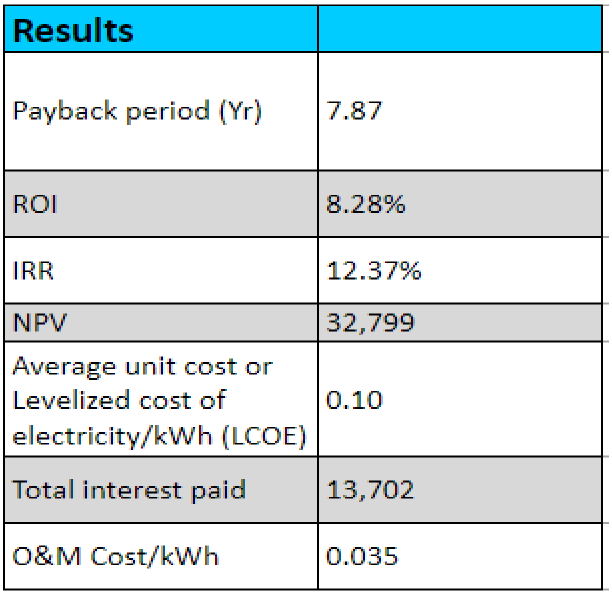
3. **Cost per Wp in USD:** Total Cost (USD)/Total Capacity (kWp)
   38,062 USD/29,480 Wp
   ≈1.291 USD/Wp
4. **Cost per Wp in HUF:** Cost per Wp (USD)×Exchange rate (HUF/USD)
   1.291 USD/Wp×365 HUF/USD
   ≈ 471.26 HUF/Wp

Tax Consideration: It is imperative to note that the aforementioned cost includes a tax of 27.5%.

Financial Model:



Assumptions				
Capacity (kWp)	29.48		Gas inc/yr	0%
Price per Wp	1.291		REB Inc/yr	5%
Project cost(CapEx)	38,062			0
Output/day/kWp (considering all types of losses)	3.34		Gas Rate	0
Salary inc.	5%		Utility H rate	0.1161
Interest Rate	6%		Diesel Cost	0
Loan Tenor	10		Gas Mix	0.0%
Grace period	1		Hungary Grid	100.0%
			Diesel Mix	0.0%



Results	
Payback period (Yr)	7.87
ROI	8.28%
IRR	12.37%
NPV	32,799
Average unit cost or Levelized cost of electricity/kWh (LCOE)	0.10
Total interest paid	13,702
O&M Cost/kWh	0.035

Table 7: Financial Model for Roof Top Model Solar EV Charging Station-2 at Alkotas Utca, Budapest [Own work, Software: Excel]

Analysis of Financial Model for Roof Top Model Solar EV Charging Station-2 at Alkotas Utca, Budapest

The table 6 summarize the financial results from an analysis of a project, presumably related to the EV Charging Station mentioned previously or another energy project. Detailed calculation has been included in the Appendix A. Here is an interpretation of the results provided:

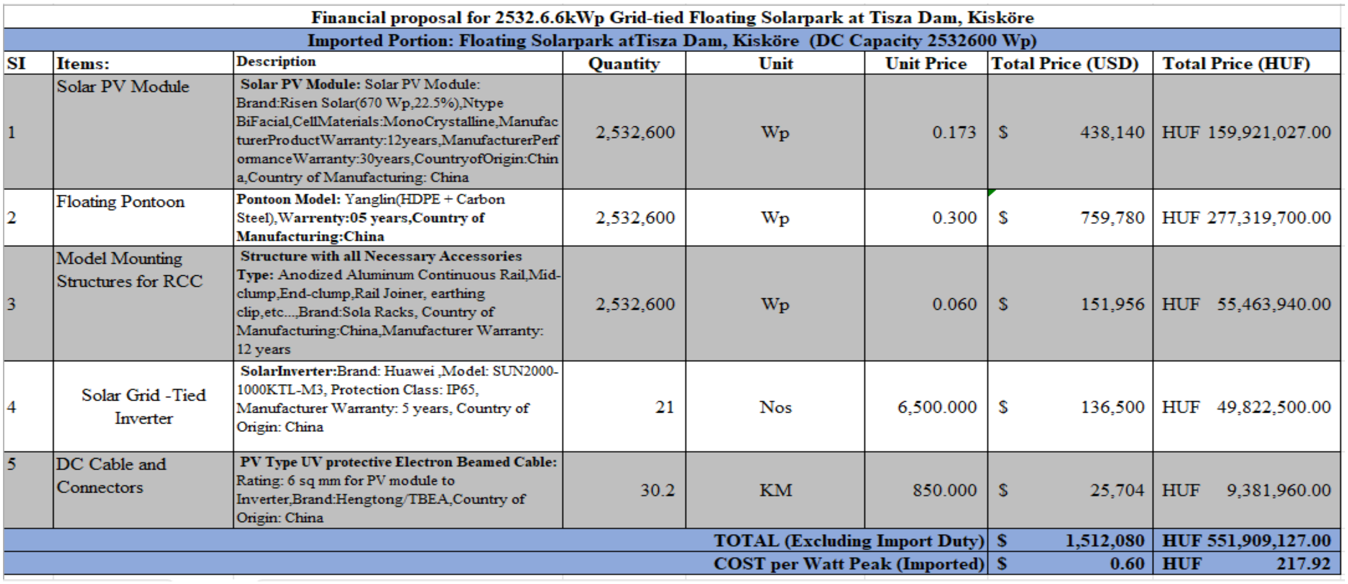
8. **Payback Period:** The project will take 7.87 years to recoup the initial investment costs. This is a relatively short payback period, which can be considered favorable in most investment scenarios.
9. **Return on Investment (ROI):** The ROI of 8.28% indicates a positive profitability outlook. This percentage shows what the return is on each dollar invested, which in this case is a 13.55% gain.
10. **Internal Rate of Return (IRR):** With an IRR of 12.37%, the project exceeds the usual benchmark for investment attractiveness. This rate is the interest rate at which the net present value of the costs of the investment equals the net present value of the benefits, suggesting good potential for profitability.

11. **Net Present Value (NPV):** The NPV of the project is 32,799. A positive NPV indicates that the projected earnings (in present dollars) exceed the anticipated costs (also in present dollars), making it a financially viable project.
12. **Levelized Cost of Electricity (LCOE):** The average unit cost or LCOE is $0.10 per kWh, which represents the per-unit cost (in this case, per kWh) of building and operating a generating plant over an assumed financial life and duty cycle.
13. **Total Interest Paid:** The total interest paid over the life of the project is 13,702, which could be related to the financing of the project. This figure is important for understanding the cost of the loan or financial leverage used in the project.
14. **Operations and Maintenance (O&M) Cost:** This is the cost of running the charging station on a per kWh basis, at $0.035. It is a critical factor for long-term financial planning as it affects the net cash flow from the project.

These financial indicators suggest that the project is economically feasible with a solid return and reasonable operational costs. The analysis seems comprehensive and reflects a well-planned project that takes into account the main financial metrics necessary for thorough evaluation.

Case 3: Floating Solar Park on Tisza Dam, Kisköre

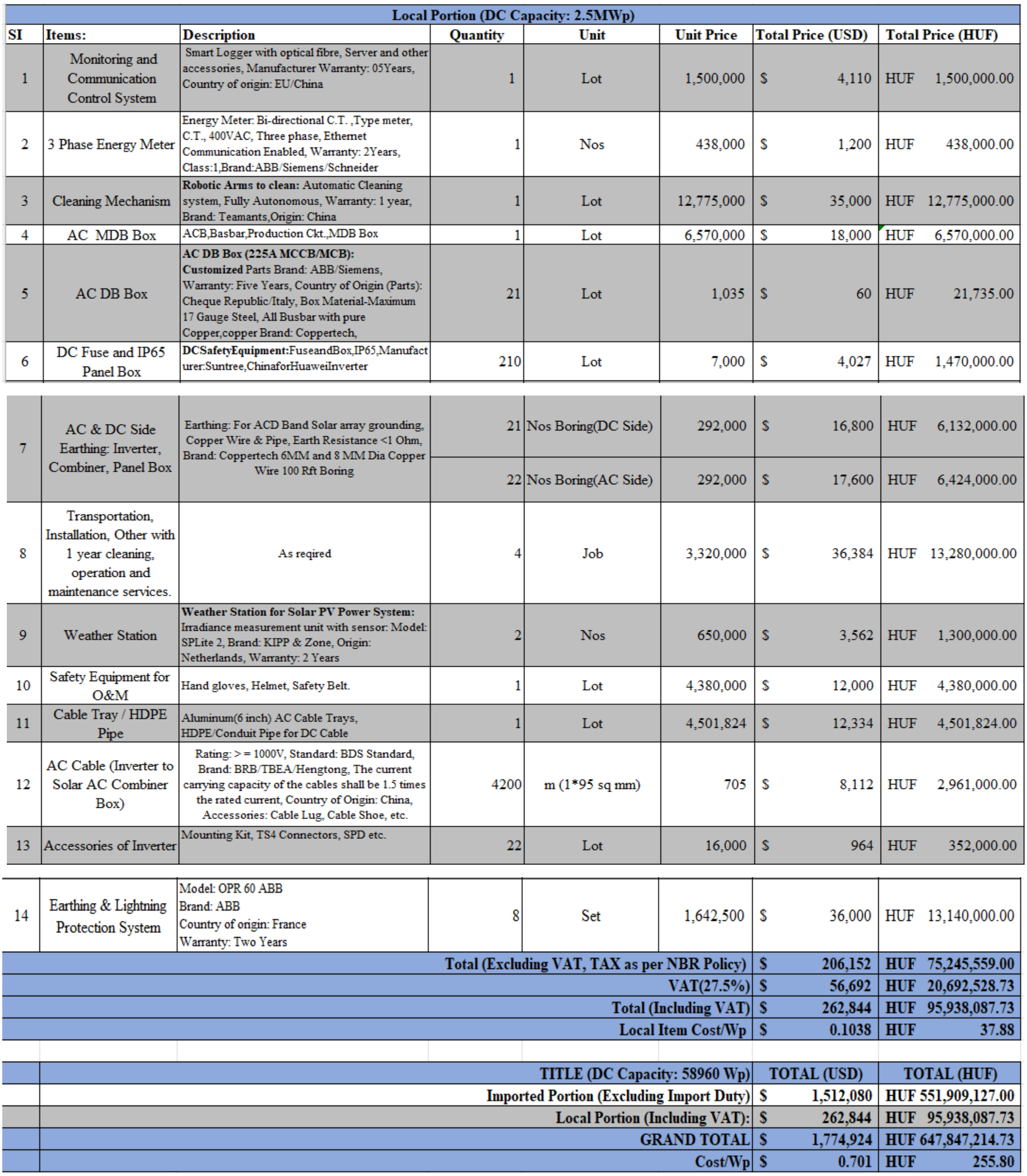
Cost Analysis



Financial proposal for 2532.6.6kWp Grid-tied Floating Solarpark at Tisza Dam, Kisköre

Imported Portion: Floating Solarpark atTisza Dam, Kisköre (DC Capacity 2532600 Wp)

SI	Items:	Description	Quantity	Unit	Unit Price	Total Price (USD)	Total Price (HUF)
1	Solar PV Module	**Solar PV Module:** Solar PV Module: Brand:Risen Solar(670 Wp,22.5%),Ntype BiFacial,CellMaterials:MonoCrystalline,ManufacturerProductWarranty:12years,ManufacturerPerformanceWarranty:30years,CountryofOrigin:China,Country of Manufacturing: China	2,532,600	Wp	0.173	$ 438,140	HUF 159,921,027.00
2	Floating Pontoon	**Pontoon Model:** Yanglin(HDPE + Carbon Steel),**Warrenty:05 years,Country of Manufacturing:China**	2,532,600	Wp	0.300	$ 759,780	HUF 277,319,700.00
3	Model Mounting Structures for RCC	**Structure with all Necessary Accessories Type:** Anodized Aluminum Continuous Rail,Mid-clump,End-clump,Rail Joiner, earthing clip,etc...,Brand:Sola Racks, Country of Manufacturing:China,Manufacturer Warranty: 12 years	2,532,600	Wp	0.060	$ 151,956	HUF 55,463,940.00
4	Solar Grid -Tied Inverter	**SolarInverter:**Brand: Huawei ,Model: SUN2000-1000KTL-M3, Protection Class: IP65, Manufacturer Warranty: 5 years, Country of Origin: China	21	Nos	6,500.000	$ 136,500	HUF 49,822,500.00
5	DC Cable and Connectors	**PV Type UV protective Electron Beamed Cable:** Rating: 6 sq mm for PV module to Inverter,Brand:Hengtong/TBEA,Country of Origin: China	30.2	KM	850.000	$ 25,704	HUF 9,381,960.00
					TOTAL (Excluding Import Duty)	**$ 1,512,080**	**HUF 551,909,127.00**
					COST per Watt Peak (Imported)	**$ 0.60**	**HUF 217.92**



Local Portion (DC Capacity: 2.5MWp)							
SI	**Items:**	**Description**	**Quantity**	**Unit**	**Unit Price**	**Total Price (USD)**	**Total Price (HUF)**
1	Monitoring and Communication Control System	Smart Logger with optical fibre, Server and other accessories, Manufacturer Warranty: 05Years, Country of origin: EU/China	1	Lot	1,500,000	$ 4,110	HUF 1,500,000.00
2	3 Phase Energy Meter	Energy Meter: Bi-directional C.T. ,Type meter, C.T., 400VAC, Three phase, Ethernet Communication Enabled, Warranty: 2Years, Class:1,Brand:ABB/Siemens/Schneider	1	Nos	438,000	$ 1,200	HUF 438,000.00
3	Cleaning Mechanism	**Robotic Arms to clean:** Automatic Cleaning system, Fully Autonomous, Warranty: 1 year, Brand: Teamants,Origin: China	1	Lot	12,775,000	$ 35,000	HUF 12,775,000.00
4	AC MDB Box	ACB,Basbar,Production Ckt.,MDB Box	1	Lot	6,570,000	$ 18,000	HUF 6,570,000.00
5	AC DB Box	**AC DB Box (225A MCCB/MCB): Customized** Parts Brand: ABB/Siemens, Warranty: Five Years, Country of Origin (Parts): Cheque Republic/Italy, Box Material-Maximum 17 Gauge Steel, All Busbar with pure Copper,copper Brand: Coppertech,	21	Lot	1,035	$ 60	HUF 21,735.00
6	DC Fuse and IP65 Panel Box	**DCSafetyEquipment:**FuseandBox,IP65,Manufacturer:Suntree,ChinaforHuaweiInverter	210	Lot	7,000	$ 4,027	HUF 1,470,000.00
7	AC & DC Side Earthing: Inverter, Combiner, Panel Box	Earthing: For ACD Band Solar array grounding, Copper Wire & Pipe, Earth Resistance <1 Ohm, Brand: Coppertech 6MM and 8 MM Dia Copper Wire 100 Rft Boring	21	Nos Boring(DC Side)	292,000	$ 16,800	HUF 6,132,000.00
			22	Nos Boring(AC Side)	292,000	$ 17,600	HUF 6,424,000.00
8	Transportation, Installation, Other with 1 year cleaning, operation and maintenance services.	As reqired	4	Job	3,320,000	$ 36,384	HUF 13,280,000.00
9	Weather Station	**Weather Station for Solar PV Power System:** Irradiance measurement unit with sensor: Model: SPLite 2, Brand: KIPP & Zone, Origin: Netherlands, Warranty: 2 Years	2	Nos	650,000	$ 3,562	HUF 1,300,000.00
10	Safety Equipment for O&M	Hand gloves, Helmet, Safety Belt.	1	Lot	4,380,000	$ 12,000	HUF 4,380,000.00
11	Cable Tray / HDPE Pipe	Aluminum(6 inch) AC Cable Trays, HDPE/Conduit Pipe for DC Cable	1	Lot	4,501,824	$ 12,334	HUF 4,501,824.00
12	AC Cable (Inverter to Solar AC Combiner Box)	Rating: > = 1000V, Standard: BDS Standard, Brand: BRB/TBEA/Hengtong, The current carrying capacity of the cables shall be 1.5 times the rated current, Country of Origin: China, Accessories: Cable Lug, Cable Shoe, etc.	4200	m (1*95 sq mm)	705	$ 8,112	HUF 2,961,000.00
13	Accessories of Inverter	Mounting Kit, TS4 Connectors, SPD etc.	22	Lot	16,000	$ 964	HUF 352,000.00
14	Earthing & Lightning Protection System	Model: OPR 60 ABB Brand: ABB Country of origin: France Warranty: Two Years	8	Set	1,642,500	$ 36,000	HUF 13,140,000.00
					Total (Excluding VAT, TAX as per NBR Policy)	**$ 206,152**	**HUF 75,245,559.00**
					VAT(27.5%)	**$ 56,692**	**HUF 20,692,528.73**
					Total (Including VAT)	**$ 262,844**	**HUF 95,938,087.73**
					Local Item Cost/Wp	**$ 0.1038**	**HUF 37.88**

	TITLE (DC Capacity: 58960 Wp)	**TOTAL (USD)**	**TOTAL (HUF)**
	Imported Portion (Excluding Import Duty)	**$ 1,512,080**	**HUF 551,909,127.00**
	Local Portion (Including VAT):	**$ 262,844**	**HUF 95,938,087.73**
	GRAND TOTAL	**$ 1,774,924**	**HUF 647,847,214.73**
	Cost/Wp	**$ 0.701**	**HUF 255.80**

Table 8: Financial Model for Floating Solar Park on Tisza Dam, Kisköre [Own work, Software: Excel]

Analysis of Cost per Unit Capacity for Floating Solar Park on Tisza Dam, Kisköre

This aims to provide an analysis of the financial aspects of a proposed Electric Vehicle (EV) Charging Station, delineating the cost associated with each unit of installed capacity.

Project Specifications: The proposed EV Charging Station is projected to have an installed capacity of 2.5 MWp.

Financial Overview: The total financial outlay proposed for this project is as follows:

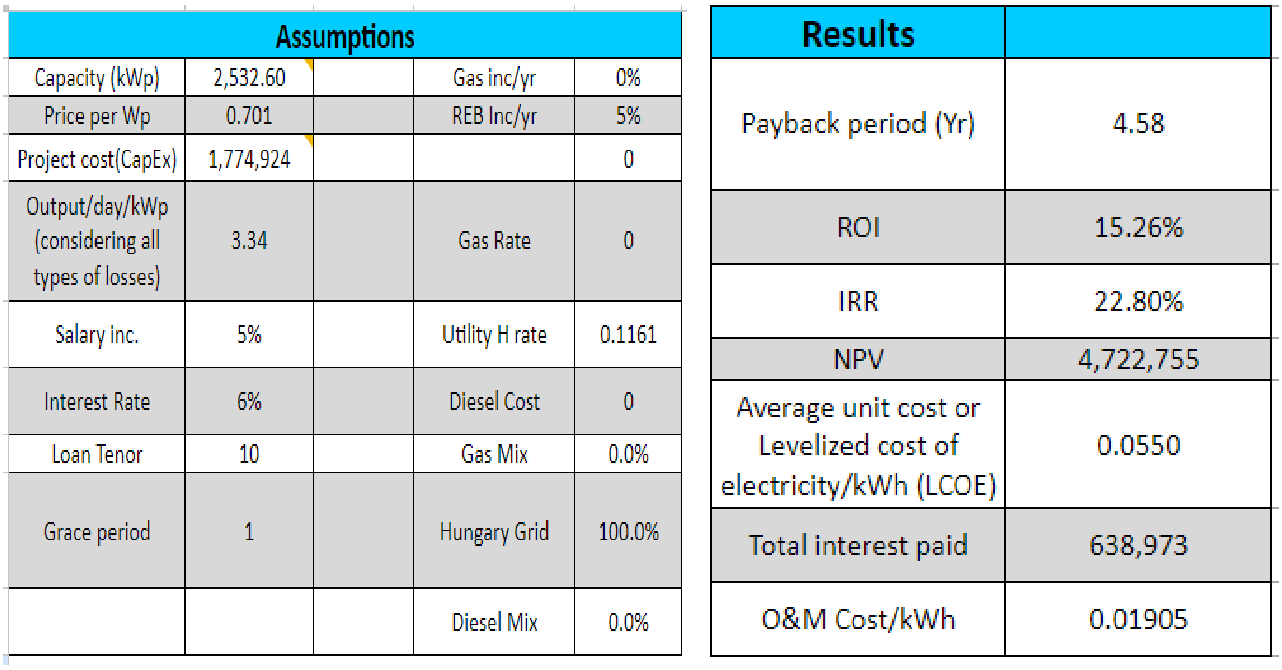
- Total Cost: $1,774,924 USD
- Equivalent Cost in HUF: 647,847,214.73 HUF (considering an exchange rate of 1 USD = 365 HUF)

Cost Analysis: To discern the cost efficiency of the installation, we calculate the cost per watt-peak (Wp) as follows:

5. **Cost per Wp in USD:** Total Cost (USD)/Total Capacity (kWp)
   1,774,924 USD/2,532,600 Wp
   ≈0.701 USD/Wp
6. **Cost per Wp in HUF:** Cost per Wp (USD)×Exchange rate (HUF/USD)
   0.701 USD/Wp×365 HUF/USD
   ≈ 255.80 HUF/Wp

7. **Tax Consideration:** It is imperative to note that the aforementioned cost includes a tax of 27.5%.

Financial Model:



Assumptions				
Capacity (kWp)	2,532.60		Gas inc/yr	0%
Price per Wp	0.701		REB Inc/yr	5%
Project cost(CapEx)	1,774,924			0
Output/day/kWp (considering all types of losses)	3.34		Gas Rate	0
Salary inc.	5%		Utility H rate	0.1161
Interest Rate	6%		Diesel Cost	0
Loan Tenor	10		Gas Mix	0.0%
Grace period	1		Hungary Grid	100.0%
			Diesel Mix	0.0%

Results	
Payback period (Yr)	4.58
ROI	15.26%
IRR	22.80%
NPV	4,722,755
Average unit cost or Levelized cost of electricity/kWh (LCOE)	0.0550
Total interest paid	638,973
O&M Cost/kWh	0.01905

Table 9: Financial Model for Floating Solar Park on Tisza Dam, Kisköre [Own work, Software: Excel]

Analysis of Financial Model for Floating Solar Park on Tisza Dam, Kisköre

The table 9 summarizes the financial results from an analysis of a project, presumably related to the EV Charging Station mentioned previously or another energy project. Detailed calculation has been included in the Appendix A. Here is an interpretation of the results provided:

15. **Payback Period:** The project will take 4.58 years to recoup the initial investment costs. This is a relatively short payback period, which can be considered favorable in most investment scenarios.
16. **Return on Investment (ROI):** The ROI of 15.26% indicates a positive profitability outlook. This percentage shows what the return is on each dollar invested, which in this case is a 13.55% gain.
17. **Internal Rate of Return (IRR):** With an IRR of 22.80%, the project exceeds the usual benchmark for investment attractiveness. This rate is the interest rate at which the net present value of the costs of the investment equals the net present value of the benefits, suggesting good potential for profitability.

18. **Net Present Value (NPV):** The NPV of the project is 4,722,755. A positive NPV indicates that the projected earnings (in present dollars) exceed the anticipated costs (also in present dollars), making it a financially viable project.
19. **Levelized Cost of Electricity (LCOE):** The average unit cost or LCOE is $0.055 per kWh, which represents the per-unit cost (in this case, per kWh) of building and operating a generating plant over an assumed financial life and duty cycle.
20. **Total Interest Paid:** The total interest paid over the life of the project is 638,973, which could be related to the financing of the project. This figure is important for understanding the cost of the loan or financial leverage used in the project.
21. **Operations and Maintenance (O&M) Cost:** This is the cost of running the charging station on a per kWh basis, at $0.012. It is a critical factor for long-term financial planning as it affects the net cash flow from the project.

These financial indicators suggest that the project is economically feasible with a solid return and reasonable operational costs. The analysis seems comprehensive and reflects a well-planned project that takes into account the main financial metrics necessary for thorough evaluation.

3.3 Comprehensive Review Analysis on Geothermal Energy in Hungary

Hungary, a country in the central Europe, has a population of around 10 million people and features Budapest as its capital. The country's economy demonstrates strengths in different economic metrics, with high technological exports and charges for the use of intellectual property standing out as important elements. In terms of energy resources, Hungary has minimal fossil fuel reserves, with the majority of confirmed reserves being coal. Renewable energy indices in Hungary, such as solar, geothermal, and wind potential, are quite low[9].

Despite Hungary's large geothermal potential and existing district heating infrastructure, the government's lack of effort in exploiting geothermal energy has been a matter of concern. The country operates roughly 180 wind turbines but may greatly boost its wind energy production by adding taller towers. Hungary's climate, with extended hours of sunshine, makes it

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[9] Energy industry in Hungary. (2023, March 23) https://aenert.com/countries/europe/energy-industry-in-hungary/ accesses 31 October 2023.

well-suited for solar power generation, and both businesses and households are increasingly turning to solar energy to battle growing energy bills. Hydropower, although less variable than wind or solar power, remains relatively insignificant in Hungary's renewable energy mix. While Hungary has the potential for renewable energy, the shift to a sustainable, renewable-based economy is a long-term enterprise and not without hurdles. F. Pikler et al. explore the global consumption of geothermal energy, with a particular emphasis on Hungary's experience [47].

The paper highlights the significance of moderate-temperature thermal water resources as a potential, yet underutilized, source of geothermal energy. Hungary's distribution of geothermal wells and favorable geothermal gradients are reviewed, showing the country's potential for geothermal energy. Additionally, the article analyzes the economic elements of geothermal heating, stating that investment costs, under favorable conditions, are equal to those of oil-heated systems, while operational expenses are much cheaper. It also addresses problems in geothermal installations, such as scale deposition and corrosion, and underlines the significance of worldwide cooperation in creating geothermal energy solutions.

Furthermore, the report covers Hungary's intentions for future expansions, including spreading geothermal heating into diverse sectors, such as agriculture and urban regions, underscoring the nation's pioneering role in geothermal energy utilization. Toth et al. dived into Hungary's geothermal potential and the production of geo-isothermal maps, filling the lack of precise geothermal mapping in the country. Hungary's geothermal resources are considerable, with geological data suggesting a geothermal gradient ranging from 37°C to 45°C per kilometer and a heat flow of 90-106 mW/m^2 [48]. The new atlas gives valuable insights, including precise maps showing temperatures of 90°C, 70°C, 60°C, 50°C, and 30°C at varied depths, catering to practical applications and facilitating investment in clean energy. The report stresses the economic issues Hungary has, with the nation importing 52% of its energy, mostly from Russia, and emphasizes the significance of reliable geothermal data to support renewable energy development. Counties like Csongrád, Békés, and Bükk Mountains stand out as prospective places, with Csongrád producing 25-30 million m^3 of thermal water yearly, supplying geothermal heating to every town in the county.

Furthermore, major initiatives, like the Miskolc-Mályi Project in Borsod-Abaúj-Zemplén County, highlight Hungary's developing geothermal-based district heating systems. Lengyel et al. provide a comprehensive assessment of Hungary's significant geothermal resources.

Hungary stands apart in Europe due to its geothermal anomaly, where hot water with temperatures ranging from 110°C to 130°C may be discovered at a depth of 2,000 meters, predominantly beneath sandstone layers holding an estimated 2,500 km3 of thermal water [49]. This precious resource has been utilized for different applications, including balneological purposes and new uses in agriculture, such as heating greenhouses and chicken farms.

Geothermal heating was originally used in the 1960s, leading to great utilization in greenhouse heating, especially at the world-leading scale of 2 million. District heating fueled by geothermal energy was launched in 1985, supplying thousands of households across various cities. The Hungarian government has played a vital role in helping the development of geothermal energy with a state-sponsored project, facilitating exploration and resource estimation. Recent attempts include the GEOTHERM Icelandic-Hungarian Joint Venture, concentrating on extending geothermal energy uses through joint ventures and spa hotels. Nevertheless, geothermal energy consumption in Hungary has problems, including economic obstacles due to high investment prices and variable water flow, as well as environmental concerns with the disposal of cooled water.

Despite these challenges, geothermal energy retains considerable promise for energy conservation, with an estimated yearly savings equivalent to nearly 100,000 metric tons of fuel oil. Nádor et al. [50] conducted a complete review of the condition of geothermal energy use in Hungary. The report includes vital statistics and data, suggesting that geothermal energy is a substantial addition to the country's energy landscape. Geothermal district heating and thermal water heating cascade systems are prominently represented in 23 municipalities, with an outstanding 223.36 MW installed capacity and annual production of 635.66 GWhth. Individual space heating, notably linked with spas, is accessible at around 40 locations, with a 77.2 MW capacity and 83.1 GWh yearly production.

Moreover, the agriculture sector plays a major role in direct geothermal use, with heating for greenhouses and plastic tents accounting for around 358 MW of installed capacity and 803 GWh of annual production. Additionally, the historical relevance of balneology in Hungary, with over 250 thermal wells generating an installed capacity of 249.5 MWt and a yearly utilization of roughly 745.5 GWhth, the development of Hungary's first geothermal power plant in Tura, boasting a 3 MWe capacity, and the growth and challenges of shallow geothermal systems, including ground-source heat pumps, are discussed. Currently, geothermal energy accounts for just 2% of Hungary's heating needs[10], with approximately 30 municipalities utilizing it. Hungary's reliance on Russia for 85% of its gas usage and the state's vested interests in the gas business further complicate the situation.

To exploit geothermal energy for a secure local energy supply and to reduce greenhouse gas emissions and energy prices, Hungary has to establish more aggressive targets for renewables and energy efficiency, together with financial incentives and support. With modest investments, Hungary may greatly boost its geothermal capacity, potentially reaching 10% of its energy supply and a fourth of its heating demand. Solar power has gained attention recently, while hydropower remains neglected. Hungary confronts a considerable energy import dependency, with natural gas and oil making up a significant share of primary energy consumption. The country's energy infrastructure has a combination of natural gas and oil facilities, along with some major power plants, such as the Paks nuclear power plant.

Hungary's energy perspective through 2030 intends to reduce emissions, produce more domestic electricity from carbon-neutral sources, and invest in renewables and energy efficiency. Hungary has been gradually increasing its renewable energy sector, with biomass as the primary source until 2015-2016. The government plans to obtain 14.65% of its energy consumption from renewables by 2020, above the EU's predicted 13%. Biomass and solar energy have made major contributions to Hungary's renewable energy mix, with 680 MW of solar capacity now in operation. Solar electricity, particularly household-scale installations, has been a focal point. Geothermal energy, although largely utilized for heating, showed promise, with 12 GWh of electricity produced in 2018, a huge rise from zero in 2016[11].

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[10] Are Renewables Sustainable in Hungary? (2022, August 16) https://www.hungarianconservative.com/articles/current/are-renewables-sustainable-in-hungary/ accessed 1 November 2023.

[11] Hungary’s vast geothermal potential – untapped. (2022, July 1) https://www.euractiv.com/section/energy/news/hungarys-vast-geothermal-potential-untapped/ accessed 2 November 2023.

Wind generating capacity is 330 MW, but recent regulatory changes and constraints have impeded its development. The launch of the METÁR system in 2017, offering feed-in tariffs and premium subsidies for renewables, has stimulated interest in solar installations. Solar and geothermal energy appear to be the future of Hungary's renewables sector, with significant potential for further development in both fields. Regarding ecology and environmental protection, Hungary exhibits promising indicators, mainly due to its lower carbon emissions, forest coverage, and freshwater withdrawals. Nonetheless, the Climate Changing Performance Index identifies areas for improvement, such as methane emissions and overall environmental performance.

Chapter 4: A Spatiotemporal Analysis and Forecasting of Electricity Generation-Mix in Hungary Using Artificial Analysis (ARIMA Model)

4.1 Introduction

This chapter discusses the approach used in forecasting renewable energy consumption over the next two decades. We also explain why the ARIMA model was used as the foundation for predicting. With a systematic approach, it emphasizes the importance of renewable energy in Hungary's energy planning, security, and sustainability.

4.2 Methodology

Planning and developing sustainable energy policies require accurate forecasts of renewable energy demand. This methodology describes the forecast of the consumption of renewable energy, with a concentration on solar energy, for the next 20 years using historical data from 2000 to 2022. The Autoregressive Integrated Moving Average (ARIMA) model, a reliable time series forecasting method that is well-liked for its capacity to identify time-dependent patterns, is the foundation of our forecasting strategy. We have opted to utilize Hungary-based energy consumption and production figures for various compelling reasons.

Firstly, Hungary, like many countries, is actively exploring renewable energy sources to diversify its energy mix and minimize its dependence on fossil fuels. This transition towards renewables accords with worldwide efforts to address climate change and attain sustainability. Our examination of Hungary's renewable energy trends provides insights into the nation's commitment to a greener and more sustainable future. Hungary's reliance on fossil fuel supplies from Russia has substantial economic and diplomatic ramifications.

By exploiting its renewable energy potential, Hungary can minimize its dependence on foreign energy sources and boost energy security. Our research shines a spotlight on the potential economic benefits of a more self-reliant energy sector. This study extends beyond the present, estimating energy production and consumption trends from 2022 to 2042 based on historical data ranging from 2000 to 2022. This forward-looking methodology helps us foresee the future of Hungary's most critical renewable energy sources. It is an important component of our study, offering useful insights for policymakers and stakeholders in

Hungary's energy sector. By studying these facts and anticipating future trends, our research adds to Hungary's energy planning, underscoring the relevance of renewables for energy security, sustainability, and economic growth.

4.2.1 Data Preparation

Data collection: The Hungary National Central Statistical Office provided the historical dataset on energy consumption, which includes solar energy, for the years 2000 to 2022. Our main data source for analysis is this dataset.

Data cleaning: To manage missing values, outliers, and inconsistencies, the dataset goes through a thorough cleaning process. To maintain the integrity of the time series, any data anomalies are resolved.

Data exploration: To obtain an understanding of historical trends, seasonality, and patterns of renewable energy use, exploratory data analysis (EDA) is carried out. In order to comprehend the data better, visualization tools are used.

4.2.2 Method Selection

In our study, we looked at various predictive models to find the best one for our forecasting objective. For dependable and accurate forecasts, choosing the right model is essential. We compared a number of well-known models, each with its own special method and mathematical foundation, in order to make an informed choice. These models underwent a thorough analysis that took into account their advantages, disadvantages, and suitability for our dataset. We sought to find a model that not only matched the characteristics of our time series data but also demonstrated excellent predicted performance by taking into account a wide range of forecasting approaches. This thorough analysis of numerous models highlights our dedication to providing reliable and accurate forecasts for the patterns of energy usage over the next 20 years.

Holt's Winter Model: A variation of the exponential smoothing model that takes into account both trends and seasonality in time series data is called Holt's Winter Model, commonly referred to as Triple Exponential Smoothing. It has three parts: level (), trend (), and seasonal (), all of which are updated at different intervals of time.

Level: $Vt = (1 - \alpha) * Vt + \alpha * Lt$ ……………………………[10]

Vt = the observed value of the time series at the time

Lt = the estimated level at the previous time

α = parameter for the trend component

Trend:

Tt = estimated trend component at time

α = parameter for the trend component

Yt = the actual observation at time

St = the seasonal component at time

m = the seasonality.

Seasonal: $St = \beta \cdot (Yt - Tt) + (1 - \beta) \cdot St - m$ ………………………………..(11)

β = parameter for the seasonal component

Tt = estimated trend component at time

Yt = the actual observation at time

m = the seasonality.

St = the seasonal component at time

Polynomial Regression: Regression using polynomials fits a polynomial function to time series data. By including polynomial terms in a linear regression model, it can capture nonlinear trends. The complexity of the model depends on the degree of the polynomial.

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \cdots + \beta_n x^n + \varepsilon. \quad \text{……………………………… (12)}$$

Support Vector Regression: Support Vector Regression is a machine learning approach that models time series data using support vector machines. It transposes the data into a higher-dimensional space and identifies a hyperplane that minimizes prediction errors while providing the greatest fit for the data.

$$\min ||w||^2 + C \sum_{i}^{n} (\xi_i^+ + \xi_i^-) \quad \text{……………………………… (13)}$$

Prophet Model by Facebook: The Facebook Prophet Model is made to predict time series data with daily observations that show trends over a range of time scales. Using additive modeling, it divides time data into trend, seasonality, and holiday effects.

$y(t) = g(t) + s(t) + h(t) + e(t)$ ……………………………. (14)

Gated Recurrent Unit (GRU): Another recurrent neural network called a GRU streamlines LSTM by employing only two gates: reset and update gates. Short- and long-term dependencies can be captured by GRU, which is effective.

Seasonal Decomposition of Time Series (STL): Time series data are divided into seasonal, trend, and residual components by STL. It is an effective tool for breaking down complicated time series.

Gaussian Process Regression (GPR): Each point in the series is viewed as a sample from a Gaussian distribution by GPR, which models time series data as a probabilistic process. It can capture forecast uncertainty.

Exponential Smoothing State Space Model (ETS): The level, trend, and seasonality of time series data are captured by ETS models using exponential smoothing. To handle varied patterns, they offer numerous versions, such as ETS (AAA) and ETS (MAM).

Arima Model: In statistics and econometrics, the Autoregressive Integrated Moving Average (ARIMA) model is a reliable and popular time series forecasting method. When working with time-dependent data, such as stock prices, economic indicators, and climate variables, where the historical observations are connected and reveal patterns over time, ARIMA models are particularly efficient. In order to give exact short- and long-term forecasting, ARIMA models seek to detect the underlying structure and patterns in a time series collection. The very versatile ARIMA model can handle a wide range of time series patterns, including trends, seasonality, and intricate interactions. They need rigorous validation and judicious model order selection to ensure credible forecasts. The ability of ARIMA to handle seasonality and exogenous variables is further strengthened by extensions like seasonal ARIMA (SARIMA) and state space models.

ARIMA Model Definition:

The autoregressive (AR) component indicates the link between the time series' present value and its historical value. The order of the autoregressive component, "p" is used to denote it in the form of AR(p). An AR (p) model is defined mathematically as:

$$X_t = \phi_1 X_{t-1} + \phi_2 X_{t-2} + \ldots + \phi_p X_{t-p} + \varepsilon_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(15)}$$

The validation set is used to optimize the parameters of the ARIMA model. For the best model fit, various p, d, and q combinations are tested.

According to our analysis, ARIMA is a good option for time series forecasting when non-stationarity in the data is present and simplicity, interpretability, and historical performance are important considerations. The specific properties of the dataset and the objectives of the forecasting activity should, however, always be taken into consideration when selecting a model. To choose the appropriate method for a specific dataset, model selection and validation should be carried out. There are a number of specific reasons why using the ARIMA (Auto Regressive Integrated Moving Average) model is preferable to alternative models.

Differencing and Stationarity: ARIMA models are built to handle non-stationary time series data. Since many time series data sets from the actual world are non-stationary, their statistical characteristics fluctuate with time. ARIMA is a good option for modeling a variety of time series because it can differentiate such data into stationary form. Differentiating is a technique that ARIMA uses to produce stationary data by reducing or eliminating trends and seasonality. When working with data that has trends or seasonality, this is quite helpful.

Simplicity and Parsimony: When compared to more complicated neural network models like LSTM and GRU, ARIMA models are comparatively simple and parsimonious. When working with scant data, simplicity might be advantageous because it lowers the chance of overfitting. The few parameters that need to be estimated for ARIMA models are p, d, and q, where p stands for autoregressive order, d for differencing order, and q for moving average order. When analyzing tiny datasets, where sophisticated models could overfit, this simplicity might be useful.

Interpretable Components: ARIMA models divide time series data into understandable parts, such as moving average (MA) and autoregressive (AR) terms. This breakdown enables a clear grasp of how prior values and prior errors affect projections for the future. Using a linear mixture of prior data and mistakes, ARIMA conveys forecasts. The time series' underlying dynamics may be better understood because of this transparency.

Historical Performance: Time series forecasting is essential in many disciplines, including finance and economics, where ARIMA has a demonstrated history of success. In multiple applications over a long period of time, its usefulness has been proven. ARIMA may be better at handling time series dynamics than Holt's Winter Model, Polynomial Regression, and Support Vector Regression, particularly when working with non-stationary data. Although Facebook Prophet, LSTM, GRU, and GPR are strong models, they can be expensive to compute and may need larger datasets to perform better than ARIMA. Alternatives include ETS, STL, and VAR, however, they might not always be as effective at capturing intricate temporal connections as ARIMA.

Evaluation: Statistical measurements like Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) are used to carefully evaluate the performance of the ARIMA model. To make sure they have white noise properties, the residuals of the model are also examined.

$$RMSE = \sqrt{(\Sigma(Pi - Ai)^2 / n)} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots..(16)$$

We anticipate renewable energy use over the following 20 years, from 2023 to 2042, using the verified ARIMA model. This extended prediction offers insightful information about potential trends. To express how uncertain the forecasts are, prediction intervals are calculated. Understanding the variety of potential outcomes is aided by this.

4.3 Results

Production and Consumption of Primary Renewable Energy Sources by Source of Energy (10):

Production

The input dataset depicts Hungary's use and production of primary renewable energy sources from 2000 to 2021. Hydro, wind, geothermal, solar, biogas, biofuels, biomass, and renewable municipal waste are all included. We can observe that traditionally, fuel energy was used and produced more, but the usage of renewable energy has increased in recent years.

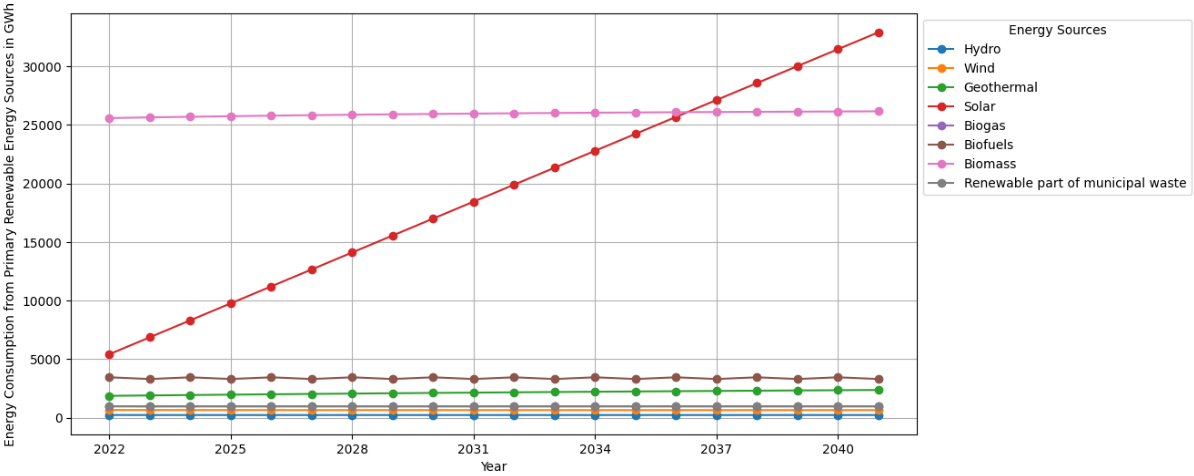


Figure 26: Projection of Production from Primary Renewable Energy Sources Until 2041 [Own work, Software: Python]

The predicted output, which spans the years 2022 to 2041, anticipates Hungary's potential renewable energy consumption and indicates a favorable trajectory, with a rise in renewable energy consumption projected during the forecast period. Hydro energy consistently contributes around 232 GWh each year. Wind energy begins at about 664 GWh in 2022 and marginally decreases to around 653 GWh by 2041. Geothermal energy shows a growth from approximately 1871 GWh in 2022 to around 2372 GWh in 2041. Solar energy consumption witnesses a notable rise, starting at 5424 GWh in 2022 and escalating to nearly 32911 GWh by 2041. Both biogas and biomass hover steadily across the years, with biogas averaging around 935 GWh and biomass at about 25965 GWh annually. Lastly, the renewable part of municipal waste remains nearly constant each year at around 975 GWh. This comprehensive data signifies Hungary's dedication to utilizing a varied spectrum of renewable energy resources, ensuring a sustainable energy future while diminishing reliance on non-renewable sources.

Consumption

The graph presents a comprehensive overview of Hungary's projected energy production from renewable sources between 2022 and 2041. Notably, hydro energy exhibits remarkable consistency, stabilizing at approximately 232 GWh annually. Wind energy, while beginning at 664 GWh in 2022, sees a minor reduction, steadying around 653 GWh by the end of the forecast period. Geothermal energy, on the other hand, starts at 1870 GWh and experiences a gradual ascent, reaching 2371 GWh by 2041. Most prominent is the solar energy sector, projected to undergo a substantial surge from 5424 GWh in 2022 to a remarkable 32910 GWh in 2041. Biogas remains relatively unchanged around 973 GWh, while biofuels see a nominal increment from 951 GWh to 998 GWh by 2040. Biomass is poised to maintain stability, initiating at 25578 GWh and concluding at roughly 26089 GWh in 2041. Lastly, the renewable component of municipal waste remains fairly constant, averaging 642 GWh. Overall, the data accentuates Hungary's progressive trajectory in renewable energy production, with a pronounced emphasis on solar energy, underscoring its potential as a significant contributor in the upcoming decades.

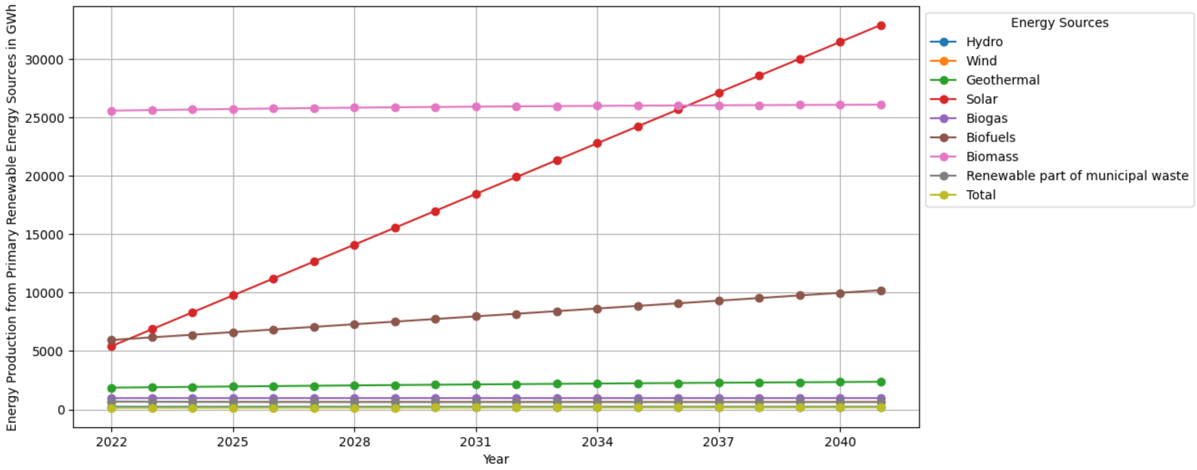


Figure 27: Projection of Consumption from Primary Renewable Energy Sources Until 2041 [Own work, software: Python]

Production of Primary Energy in Calorific Values

From 2000 through 2021, the input dataset shows Hungary's use of primary renewable energy sources. Coal, petroleum and petroleum products, natural gas, combustible renewables and wastes, nuclear power, hydropower, wind power, and other non-combustible renewables are among these sources. There has also been a shift in recent years toward higher usage of renewable energy sources, showing a growing emphasis on sustainability and less reliance on traditional fuel sources. A consistent consumption of coal is observed throughout the period, stabilized at approximately 1000 GWh. Petroleum and petroleum products exhibit a gradual ascent from 12618 GWh in 2022 to 12776 GWh by 2041. Conversely, natural gas usage remains relatively invariant, approximating 13610 GWh annually. A noticeable trend is discerned in the consumption of combustible renewables and wastes, initiating at 34135 GWh in 2022 and culminating at 35551 GWh by 2041. Nuclear power, another significant contributor, progresses from 48202 GWh in 2022 to 50705 GWh in 2041. Hydropower's contribution remains steadfast around 205 GWh annually. A slight decline is evident in wind power utilization, descending from 594.50 GWh in 2022 to 540.40 GWh by 2041. Most prominently, other non-combustible renewables surge from 7679.40 GWh in 2022 to a substantial around 20000 GWh in 2041. In summation, Hungary's future energy paradigm underscores a commitment to diversifying its energy portfolio, with an appreciable shift towards sustainable and non-traditional renewables, ensuring a pragmatic and environmentally conscious energy trajectory for the subsequent two decades.

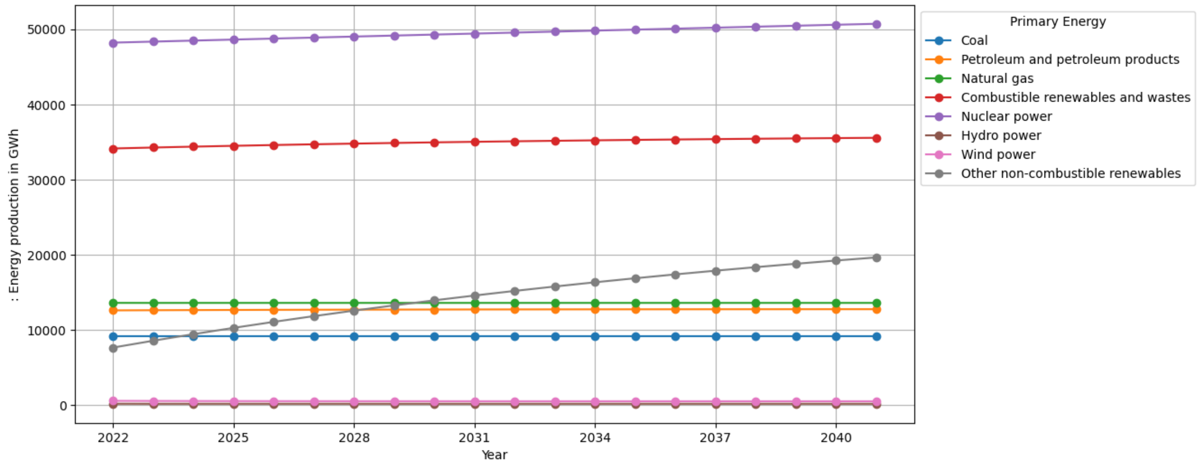


Figure 28: Projection of Production of Primary Energy Until 2041 [Own work, software: Python]

Gross Electricity Production

The input information contains a variety of elements that contribute to Hungary's Gross Electricity Production from 2000 to 2022. These constituents include nuclear, coal, and coal products, petroleum products, biomass, biogas, renewable municipal waste, hydro, wind, solar, and geothermal. The graph delineates Hungary's gross electricity production spanning from 2022 to 2041. Nuclear energy, a dominant component, remains relatively stable throughout the period, hovering around 15862 GWh. The coal and coal derivatives category start at 2908 GWh in 2022 and demonstrate a consistent decline, reaching 893 GWh by 2041. Natural gas follows a similar trajectory, beginning at 8667 GWh and reducing to 8529 GWh over the two-decade span. Interestingly, the petroleum products category exhibits negative values, suggesting a possible net consumption or decrease in stored energy. Biomass and biogas exhibit slight fluctuations, but generally stabilize around 1654 GWh and 1663 GWh, respectively.

The renewable energy sectors project a promising growth trend. Hydroelectric energy maintains consistency at approximately 202 GWh. Wind energy starts at 207 TWh and sees a moderate increase to 549 GWh by 2041. The most pronounced growth is observed in solar energy, which initiates at 6487 GWh and leaps dramatically to 12850 GWh by the end of the forecast period. Geothermal energy remains fairly stable at around 315 GWh, with negligible fluctuations. Other sources experiences minor variations but roughly averages 302 GWh throughout the examined timeframe. In summation, Hungary's electricity production landscape over the projected period indicates a paradigm shift towards renewable sources, particularly solar energy. The reduction in coal and natural gas usage, coupled with the surge in renewables, underlines Hungary's commitment to sustainable energy transitions and decarbonization strategies in the electricity sector.

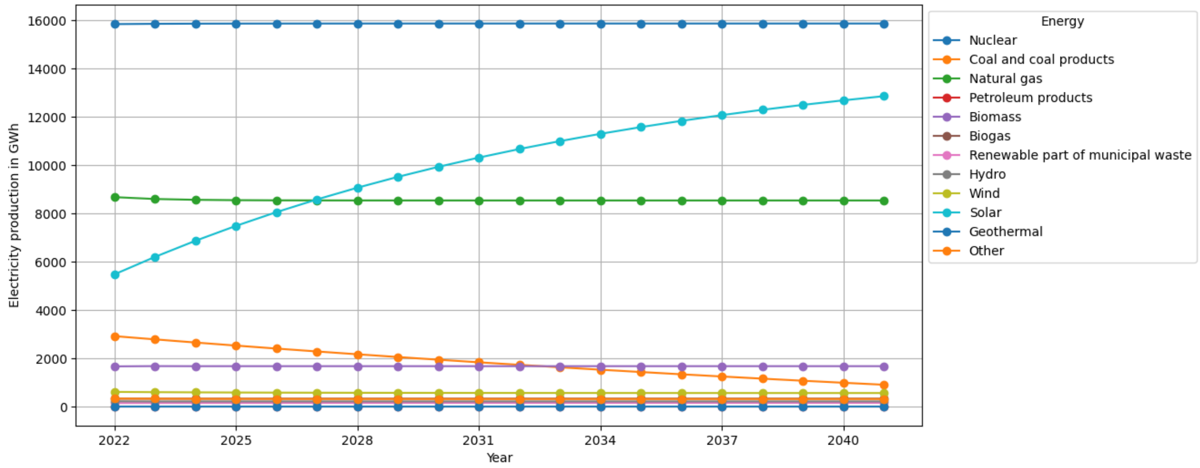


Figure 29: Projection of Gross Electricity Production Until 2041 [Own work, software: Python]

Share of Use of Renewable Energy Sources in Gross Final Energy Consumption

From 2000 to 2021, this graph depicts the Share of Renewable Energy Sources in Gross Final Energy use, which includes aspects relating to electricity use, heating and cooling, and transportation. During that time period, there was a considerable increase in the usage of renewable energy in electricity consumption as well as the heating and cooling sectors. Over the years, power consumption exhibited a modest increase, from 14.63 % in 2022 to 15.40 %

in 2041, demonstrating a consistent growth tendency. In contrast, heating and cooling displayed a modest reduction, with values decreasing from 17.76% in 2022 to 17.15% in 2041. Similarly, the transport sector showed a fall, decreasing from 8.75 % in 2022 to 7.77% in 2041, implying a contraction in consumption in this sector as well. Our estimate also predicts that in the next two decades, these sectors will be entirely reliant on renewable energy. Though the transportation sector has room for development, there are various reasons why renewable energy should not be used in this sector. Because of existing infrastructure, such as gasoline and diesel refill facilities, the transportation sector relies significantly on traditional fossil fuels. Transitioning to renewable energy sources, such as electric vehicles (EVs), necessitates a major revamp of infrastructure, such as charging stations and battery technologies. Furthermore, because fossil fuels have a high energy density, they are suitable for long-distance transit and heavy-duty applications. While ecologically benign, renewable energy sources such as batteries and hydrogen may not provide the same energy density and range, which can be a hindrance for some transportation needs.

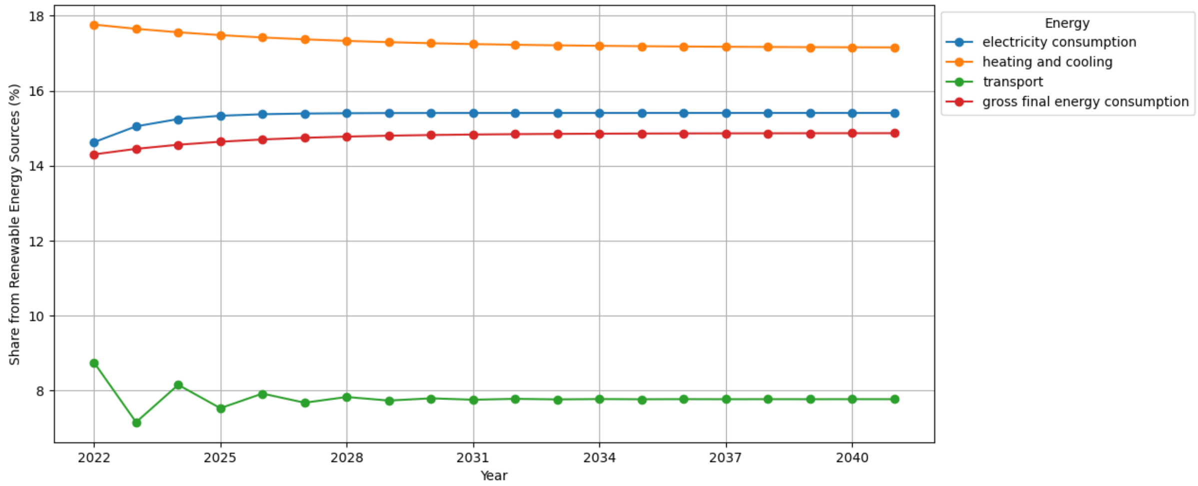


Figure 30: Projection of Share of Use from Renewable Energy Sources in Gross Final Energy Consumption Until 2041 [Own work, software: Python]

Share of Electricity Produced from Renewable Energy Sources

This graph represents the forecast of the share of electricity generated by renewable energy sources. Hydro and wind power have continuously performed well throughout the years, contributing significantly to the share of electricity generated by renewables. Their performance has been consistent, and they continue to be important contributors. Solar energy has made a significant contribution over time, and it is predicted that by 2041 around

115 GWh energy could be generated from Solar. Biomass energy production started at 20.31GWh in 2022 and exhibited a progressive reduction, reaching 17.14 GWh in 2041. Biogas output remained generally consistent, with a modest fall from 4.38 GWh in 2022 to 4.34 GWh in 2041. Wind energy production also marginally fell from 8.42 GWh in 2022 to 6.89 GWh in 2041. The data reveals a move towards higher reliance on certain renewable sources while others remain stable or fall marginally. While it had little presence in 2000, it has seen significant expansion in recent years (2020-2021). This demonstrates a growing trend toward using solar energy to generate power. Biomass and biogas, on the other hand, have been very consistent providers, with some swings. They are still present, although their expansion has been low in comparison to other sources. Our forecast expresses solar energy's dominance over the next two decades.

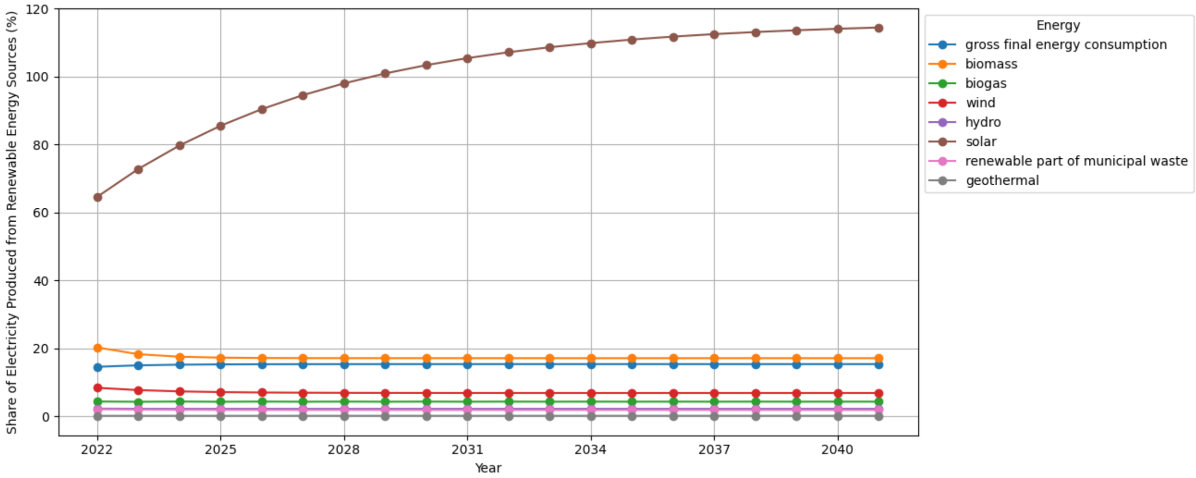


Figure 31: Projection of Share of Electricity Produced from Renewable Energy Sources Until 2041 [Own work, software: Python]

Share of Renewable Energy in Energy vs Share of Renewable Energy in Electricity

Share of renewable energy in Energy vs share of renewable energy in Electricity presents Hungary's evolving commitment to renewable energy from 2022 to 2041. Over the span of these two decades, the share of renewable energy in the country's overall energy consumption sees a steady rise from 14% in 2022 to about 16% by 2041. Meanwhile, a parallel yet more pronounced growth is observed in renewable energy's contribution to electricity consumption. Starting at 15% in 2022, it reaches 25% by 2041. This suggests not only a consistent national shift towards renewable energy sources but also indicates that the electricity sector is spearheading this transition with a faster adoption rate compared to the broader energy sector.

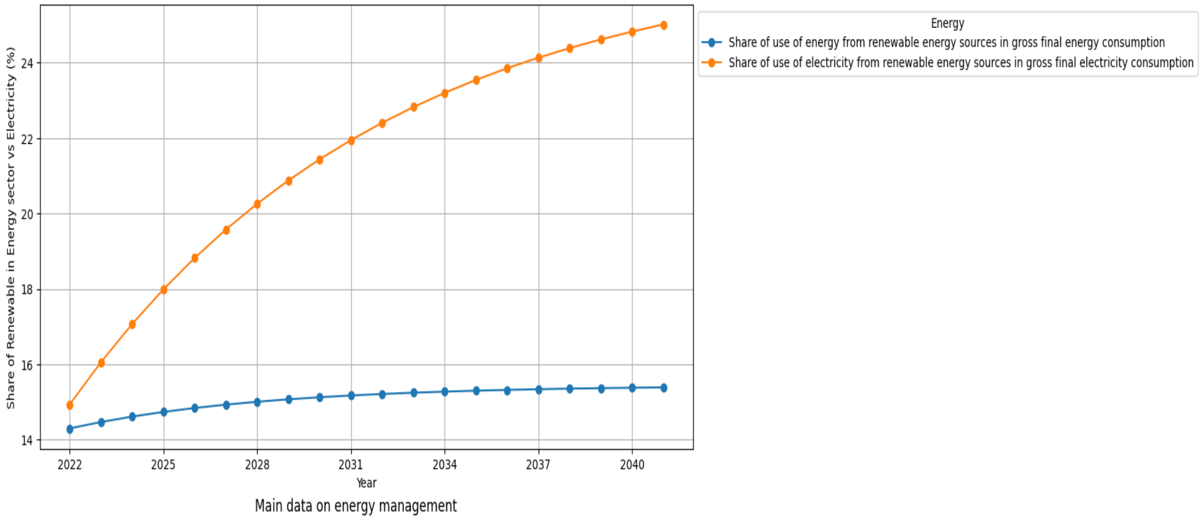


Figure 32: Projection of Share of Renewable Energy in Energy vs Share of Renewable Energy in Electricity Until 2041 [Own work, software: Python]

Primary Energy Balance

Primary energy balance graph provides an overview and gives a clear prediction of Hungary's energy situation from 2022 to 2041. From 2022 to 2041, Hungary's energy production starts at about 124710 GWh and slightly drops to 122822 GWh by the end. This means that over these 20 years, while energy production reduces a bit, it doesn't change drastically. Throughout this period, imports consistently maintained at 235227 GWh. Exports, starting at 42629 GWh in 2022, display minor fluctuations but average around 42905 GWh over the two decades. Lastly, when we look at the total energy consumed, it starts at 304041 GWh in 2022 and settles close to 304778 GWh by 2041. So the projection about Hungary's energy landscape over these two decades is steady. Production dips a little, imports stay the same, exports wobble a bit, but overall consumption remains pretty stable.

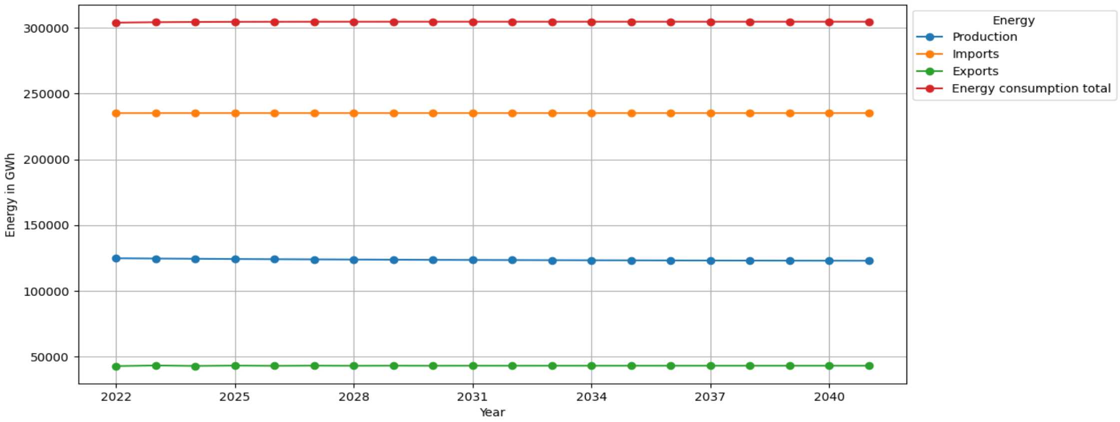


Figure 33: Projection of Primary energy balance Until 2041 [Own work, software: Python]

Energy Dependency

Energy dependency provides a chronological overview of Hungary's reliance on energy imports in relation to its total energy consumption from 1990 to 2042. In 1990, Hungary's energy dependency stood at 46%, indicating that nearly half of its energy consumption was sourced from imports. This ratio experienced fluctuations, reaching its highest at 63% in 2006. This suggests that in that year, a significant majority of Hungary's energy needs were met through imported sources. Following 2006, there was a notable reduction, with the ratio dipping to 49% by 2013. However, starting from 2023, there appears to be a stabilization in Hungary's energy dependency, consistently hovering around 61% for two decades. Analyzing this data, it's evident that Hungary's energy consumption patterns have varied, but there remains a significant dependence on import energy from other countries specifically from Rasia across the years.

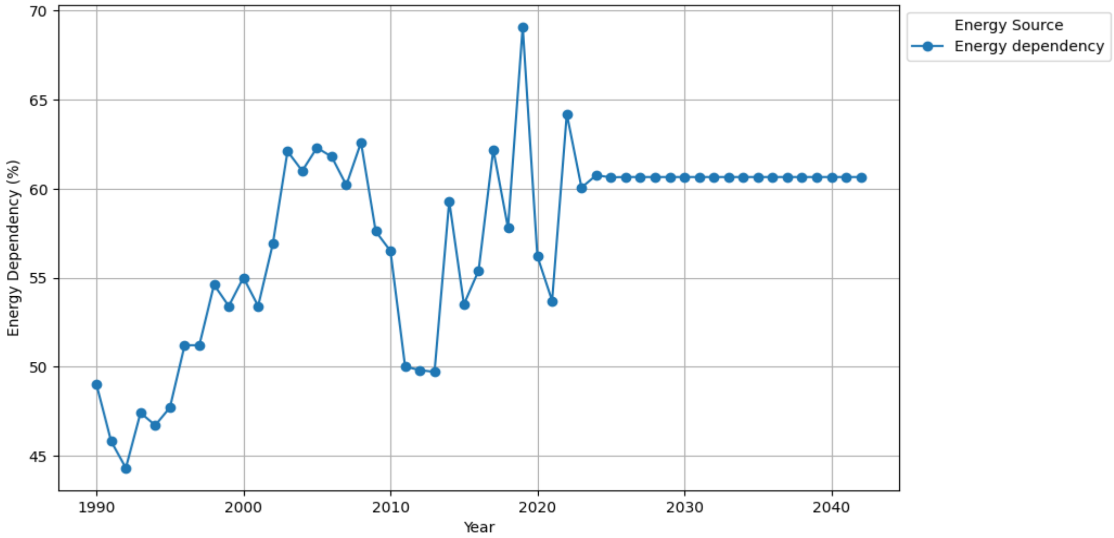


Figure 34: Projection of Energy Dependency Until 2041 [Own work, software: Python]

Several important conclusions are drawn after studying the dataset. At first glance, it is clear that Hungary has made great progress toward diversifying its energy supply, with a noteworthy rise in the proportion of renewable energy sources over time. Notably, the use of Solar energy has increased significantly, reflecting a global movement to tap into these renewable resources. Our analysis and predictive models show that this positive trend is likely to continue over the next two decades. ARIMA model predicts that the share of renewable energy sources will continue to expand, with solar energy in particular primed for large growth.

Chapter 5: Hungary Energy Policy Review and Analysis

5.1 Introduction

In the context of global concerns over climate change and the urgent need to shift towards sustainable and renewable energy sources, Hungary has established ambitious objectives for its energy strategy, outlining a long-term trajectory that spans until the year 2040. The dedication of the Hungarian government to attaining these objectives signifies a noteworthy advancement towards a more sustainable and ecologically conscious energy framework. Central to this vision is the usage of renewable energy sources, with the integration of photovoltaic (PV) technology into electric car charging stations serving as a crucial element of this shift.

The objective of this policy assessment is to conduct a thorough evaluation of the viability and efficacy of Hungary's 2040 energy objectives, with specific emphasis on the incorporation of photovoltaic (PV) technology into the infrastructure for charging electric vehicles. Through conducting a thorough analysis, our aim is to assess the compatibility between these objectives and the anticipated results of our investigation. The chapter aims to shed light on the implications, challenges, and potential benefits of this policy initiative. The results of our study will provide significant contributions to policymakers, stakeholders, and individuals dedicated to promoting a sustainable and ecologically aware future in Hungary.

5.2 Energy Policy Review Focusing on Solar Power

The energy revolution has quickly spread throughout the globe, influencing energy supply systems and the ways in which individuals and businesses may aid in speedy decarbonization. As solar and wind energy progressively displace coal, natural gas, and nuclear energy as the world's primary energy sources, the power sector is taking the lead in the shift.

The EU has committed in 2030 climate and energy framework to a clean energy transition that will help achieve the climate change objectives of the Paris Agreement and offer clean energy to everyone uphold this commitment, the EU has set legally binding climate and energy targets for 2030, which include a minimum 40% reduction in greenhouse gas emissions, a minimum increase in energy efficiency, a minimum increase in the share of renewable energy in EU energy use, and a minimum 15% level of electricity interconnection between neighboring Member States [60].

To elaborate further, The European Parliament and the Council passed Regulation (EU) 2018/1999 in 2014, establishing a 2030 Framework for Energy and Climate for the Union. It is based on four major Union-level targets: a reduction of at least 40% in overall GHG emissions, an indicative target of at least 27% improvement in energy efficiency, to be reviewed by 2020 with a view to raising the level to 30%, an at least 27% share of renewable energy consumed in the Union, and at least 50% electricity interconnection. It was said that the Member States' contributions will be driven by the need to meet the Union's binding renewable energy target. An amendment to Directive 2009/28/EC of the European Parliament and of the Council established a new, obligatory target for the Union's renewable energy share of at least 32% for the year 2030. With a provision for a review with a view to upgrading the Union-level objectives, the European Parliament and Council modified Directive 2012/27/EU to set the Union-level aim for energy efficiency improvements in 2030 to at least 32,5%. [61]

The governments of Europe and members of the European Parliament approved a comprehensive package of EU regulations between 2014 and 2018, defining new, legally enforceable goals for energy and climate policy in Europe with a focus on 2030. The Member States of the European Union will achieve the following goals by 2030:

1) cut their greenhouse gas emissions by 40% compared to 1990 levels

2) improve their economies' energy efficiency by 32.5% compared to a baseline; and

3) increase the proportion of renewable energies in final energy consumption from roughly 20% today to 32% in 2030. A political vision for attaining a Net Zero economy by 2050 was also provided by the European Commission in November 2018 together with the analytical underpinnings for the creation of an EU long term strategy for climate and energy policy [62].

The report Renewables 2022, Analysis and Forecast to 2027 by the International Energy Agency is based on recent changes in market conditions and policy of the industry of renewable energy. It projects the adoption of renewable energy technologies for power, transport, and heating through 2027 while also examining the major issues facing the sector and identifying roadblocks to quicker expansion [66].

The report specified, as in recent years the European Commission predicts that in order to achieve the REPowerEU plan's goal of drastically reducing reliance on Russian fossil fuels by 2027, the percentage of renewable energy in the power, transport, and heating sectors would need to be significantly increased although none of these sectors' levels are in line with the REPowerEU strategy.

Supporting the previous argument the report provided an example, the proportion of renewable energy in electricity increases to about 55% by 2027, but this is still much less than the 69% share that the European Commission believes is required to sustain the REPowerEU plan. Governments across the European Union will need to reduce policy uncertainty, streamline the permission process, and quicken transmission and distribution network improvements in order to support additional growth. Expanding the use of renewable energy in the heating and transportation sectors also requires increasing the production of renewable electricity, which can be used to generate green hydrogen and power heat pumps and electric cars.

The report also cited as a primary instance, the predicted REPowerEU demand for transport is less than half, or 16%, of renewable energy by 2027. To restrict or decrease energy demand and increase the percentage of renewables in final energy consumption, member states will need to harmonize their domestic policies, quicken the deployment of biofuels, and strengthen conservation and efficiency measures.

According to the European Energy Transition 2030: The Big Picture report, for the desired shift in energy transition, wind and solar to make up more than half of the growth in renewable energy generation, they must both triple in size. In the scenarios presented by the Commission, relative growth for biomass will be less than 50%, but absolute growth would be highest. Hydro and geothermal energy will increase a little. Renewable energy sources will be employed more and more in heating, cooling, and transportation, with the electricity sector being their most significant use. In addition to the direct use of renewables like solar thermal, geothermal, and biomass for heating and cooling as well as advanced biofuels in transportation (primarily for aviation and shipping purposes), deep decarbonization will be facilitated by these methods as well [63].

In recent years, the cost of energy produced by wind and solar power facilities has significantly dropped. New wind and solar projects are now more cost-competitive than new coal, gas or nuclear power facilities in a growing number of global countries [64].

Costs will continue to decrease, according to the results of competitive bidding for projects that will be completed over the next few years. Prices for solar and wind energy have been as low as 3 cents per kilowatt hour globally, and bids as low as 5 cents have been made in a number of EU Member States. A crucial economic tipping point will soon be reached when running current fossil fuel facilities will become more expensive than developing new wind and solar projects in the EU [65].

According to EU legislation, each Member State of the EU must create a 10-year National Energy and Climate Plan (NECP) in order to meet the EU targets. This plan must include a binding national target for reducing greenhouse gas emissions that are not already covered by the EU Emissions Trading System (ETS). The NECP drafts have all been examined by the European Commission.

Hungary has taken into consideration existing national goals, programmes, and policies in the National Energy and Climate Plan (NECP). The new National Energy Strategy, which is being developed at the same time as the NECP, and the NECP's development are closely tied in terms of substance and development. The plan also aligns with the policy directives outlined in the First Climate Change Action Plan (CCAP) and Second National Climate Change Strategy (NCCS 2), both of which were approved by Parliament in the autumn of 2018 as well as with the National Development and Spatial Development Concept, which outlines Hungary's development and spatial development goals through 2030.

The main goals of the new energy strategy of the National Energy and Climate Plan (NECP) are to increase energy security and sovereignty, maintain savings from lower overhead costs, and achieve the decarbonization of energy production, which can only be done by utilizing both nuclear power and renewable energy sources simultaneously. Energy sovereignty is a matter of welfare, economics, and national security for nations like Hungary which have limited access to traditional energy sources [68].

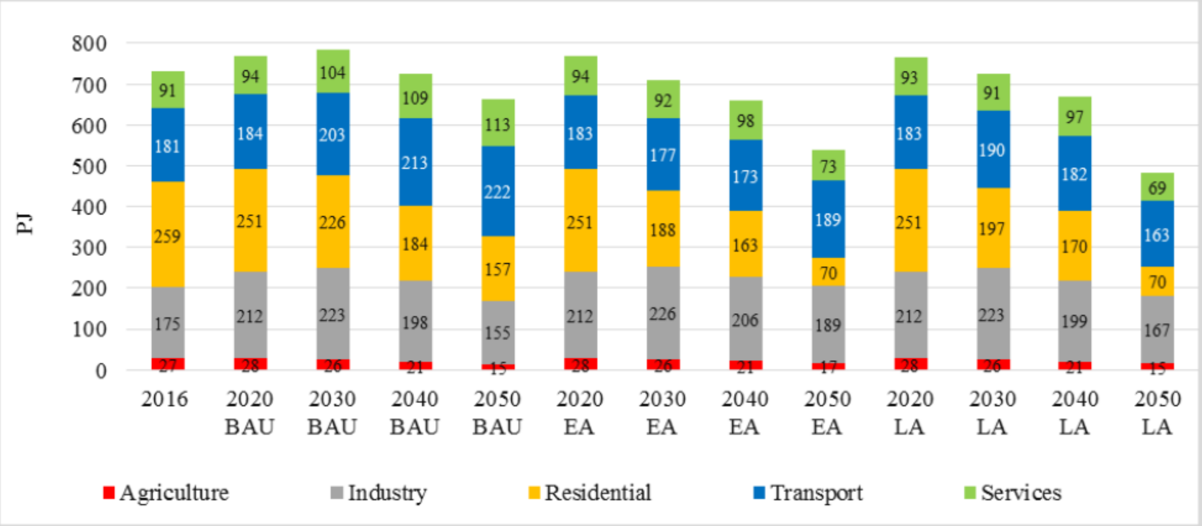
In accordance with the Second National Climate Change Strategy, which was approved in 2017, Hungary has established climate goals until 2030 with an eye towards 2050. Stronger integration of policies and measures in line with goals and targets would be beneficial for a solid final plan.

In the support of EU climate goal Hungary wants to cut its greenhouse gas emissions by at least 40% by 2030 compared to 1990, which means that in 2030, total emissions cannot exceed 56.19 million t CO2eq, a reduction of 7.6 million t CO2eq from the amount for 2017 according to National Energy and Climate Plan.

According to the National Clean Development Strategy 2020-2050, 2021 claims that Hungary starts this endeavor from a strong position, being among the few countries since 1990 where the gross domestic product (GDP) has increased while CO2 emissions decreased, by 33%. This confirms that climate protection, economic growth, and energy security are not necessarily conflicting objectives [69].

The energy sector, which includes the energy supply and consumption of other sectors (such as tertiary or residential sectors) as well as the industry, transportation, and other sectors, plays the largest influence in lowering emissions.

In the report, Eurostat data projection based on HU-TIMES modeling explains that the ultimate energy usage between 2016 and 2050 may be decreased from 733 PJ to 662 PJ under the Business-as-usual (BAU) scenario. This, however, would not be sufficient to achieve climate neutrality by 2050. By 2050, the Early Action (EA) climate neutrality scenario and Late Action (LA) climate neutrality scenarios predict that the ultimate energy consumption will be 538 PJ and 484 PJ, respectively. The projection indicates how early and late action can create a significant impact on Hungarian emission reduction measures with the timeline.



Source: Eurostat data, projection based on HU-TIMES modeling results.

Figure 35 – Composition of final energy consumption by sector under the three scenarios examined, 2016–2050 (Source: Adapted from National Clean Development Strategy 2020-2050 report)

According to the National Energy and Climate Plan in Hungary, the proportion of renewable energy in 2017's gross final energy consumption was already 13.3%. With the use of biomass, the proportion of renewable energy in gross final energy consumption rose from 1994 to 2017 from 2.2% to 7.5% for power consumption, from 0.9% to 6.8% for transportation, and from 6.5% to 19.6% for heating and cooling. The heating industry in Hungary makes the most of its potential for utilizing renewable energy; in 2016, 83% of it was utilized for heating and cooling, 9% for the production of electricity, and 8% for transportation [68].

As the transportation sector contributes to a significant level of total carbon emission, Hungary wants to use a minimum of 14% renewable energy in the transport sector by 2040. To achieve this goal, Hungary will raise the proportion of first-generation biofuels derived from food crops and fodder plants in the final energy consumption of transportation to around 7% and the proportion of second-generation (or advanced) biofuels derived from waste and biogas to 3.5%.3 By significantly increasing the use of electricity in transportation, the remaining portion of the aim will be reached. Hungary aims to get at least 20% of its total final gross energy consumption from renewable sources by the year 2030. The growth of PV capacity, which will increase from just under 680 MW in 2016 to almost 6 500 MW by 2030, is at the centre of "greening" the power sector.

According to Hungary Policy Review, 2022 by the International Energy Agency found the increasing trend of solar power generation as a renewable energy source in Hungary. With the exception of solar, which experienced a dramatic growth from 70 MW in 2017 to 1 839 MW as of the end of February 2022 (excluding standalone PV), the installed capacity of power production sources has stayed steady [70].

From 1 MW in 2010 to 1 400 MW in 2019, the total installed capacity of solar PV rose significantly since 2016, driven by the wide deployment of solar PV and by 1 April 2022, it had surpassed 3 000 MW. The government's main objective for renewable energy in the electrical sector is to increase the deployment of solar power. By 2030, the government hopes to have a solar power capacity of 6.5 GW and by 2040, 12 GW, or more than 6 000 MW. Solar PV made up 7% of Hungary's power mix in 2020.

As a promising project, without any financial assistance in 2021, an investment in a utility-scale solar PV plant was made, only depending on the anticipated increase in European power costs going forward. A 1.3 MW solar power plant in Tolna, central Hungary, was created as part of the project by Dutch company Photon Energy.

According to the Hungarian National Clean Development Strategy 2020-2050 Report, the government introduced a new grant program for families with salaries below the average Hungarian income in October 2021. It is anticipated that two-thirds of the recipients will get assistance with mounting solar panels on their roofs and that a further third will receive assistance with updating their windows and electrifying their heating systems (by installing heat pumps). The program aims to have at least 200,000 households with roof-mounted PV panels with an average capacity of 4 kW by 2030 [69].

Together with refundable subsidies from operational programs, support for the installation of PV panels intended to replace power usage for individual and communal uses is envisaged for the programming period of 2021–2027.

5.3 Energy Policy Analysis

Although the government's renewable energy goals for the electrical sector are highly ambitious, they are consistent with the nation's growing trend and potential for solar power and the forecast of the study supports the trend as well.

As the government's main objective for renewable energy in the electrical sector is to increase the deployment of solar power and by 2030, the government hopes to have a solar power capacity of 6.5 GW and by 2040, 12 GW, or more than 6,000 MW.

This goal is amply supported by the projected value of solar power generation for 2030 in the study. Hungary is positioned to produce a significant quantity of solar energy with an installed capacity of 6.5 GW by the year 2030 and according to the projection of the study by the same year, the solar capacity will reach 8.554 GW which is more than the target and justifies the national policy.

Similarly, the projected value for the next decade is also significantly promising. 16.554 GW of solar power is expected to be produced in the year 2040 and the Hungarian government's goal of doubling solar capacity by that year is 12 GW. The substantial increase in solar power generation and the projected value exceeding the national target is noteworthy, reasonable, and well-founded. In the decade of 2050, solar energy may be a major component of Hungary's energy mix which will improve its energy security and help it reach renewable energy and climate targets.

In the year 2020, solar photovoltaic (PV) energy accounted for 7% of Hungary's overall power composition. This demonstrates the increasing significance of solar energy in the nation's power production, and it is anticipated to assume an even more prominent position in the foreseeable future.

As per The National Energy and Climate Plan, Hungary aims to get at least 20% of its total final gross energy consumption from renewable sources by the year 2030. In our projection, the share of renewable energy in the country's overall energy consumption sees a steady rise from 14% in 2022 to about 37% in 2030 and 39% by 2041 over the span of two decades with the current set up which does meet the target.

Hungary wants to use a minimum of 14% renewable energy in the transport sector by 2030. However, our projection shows that the recent renewable energy consumption trend in the transportation sector showed a fall, decreasing from 8.75 % in 2022 to 7.77% in 2041, implying a contraction in consumption in this sector. The projected value of the National Energy and Climate Plan supports the targeted 14% renewable share in the transportation sector to 16.9% by 2030 as a result of additional measures which have not yet been detailed.

For both cases, introducing a PV system in the EV charging station can contribute as one of the potential measures. Our estimate predicts that with necessary developments in the next two decades, these sectors will be able to meet the targets easily and it is possible for the transportation sector to be entirely reliant on renewable energy. The transportation sector has room for development in terms of the shift towards renewable energy share.

Chapter 6: Discussion and Conclusion

This thesis has delved into the multifaceted aspects of renewable energy implementation with a particular focus on the spatiotemporal analysis and forecasting by AI utilizing the ARIMA Model. Furthermore, it has scrutinized the existing Hungarian energy policies to understand their alignment and support for renewable energy initiatives.

The long-term dependence of Hungary on fossil fuels and nuclear energy serves as an indicative representation of a more extensive pattern that has been visible in numerous European countries. The Paks Nuclear Power Plant's significant presence along the Danube River serves as an indicator to a strategic dedication to nuclear energy, in contrast to the worldwide trend towards renewable alternatives. This reliance gives rise to inquiries regarding the equilibrium of energy policies that seek to guarantee energy security while also making a commitment to sustainable energy sources.

Despite Hungary's gradual transition away from conventional energy sources, the potential of renewable energy sources in urban areas, especially solar and geothermal power, is growing in prominence. The Pannonian Basin's abundant solar radiation and geothermal potential are resources that the nation possesses that have the potential to be utilized more efficiently. In order to effectively integrate renewable energy sources into urban environments, inventive strategies are required, including the integration of solar technologies into building designs and the utilization of geothermal resources to supply district heating. The exploration of wind, hydropower and biomass as renewable options has been met with environmental and economic concerns. Hungary’s geographical constraints limit the potential for traditional wind and hydropower projects. Similarly, the prospects for urban biomass energy are complicated by issues of pollution, logistics, and social acceptance. These challenges highlight the need for a strategic approach that prioritizes environmental sustainability and public health alongside energy production.

6.1 Energy mixing

Upon conducting an exhaustive analysis, it has been discerned that augmenting renewable energy consumption within Hungary's urban locales necessitates prioritizing solar and geothermal energies. Solar energy emerges as an efficacious means to fulfill electricity demands, while geothermal energy can be earmarked for district heating systems. Despite being a potent source of non-combustible renewable energy, it is evident that Hungary currently lacks an adequate number of solar parks. According to Statista there are around 3,000 EV Charging stations in Hungary and the trend is facing a sharp rise.[12]Should the government endeavor to incorporate photovoltaic (PV) systems at these charging stations, a substantial number of vehicles could leverage this power source.

This research delineates two models, accompanied by simulations and cost analyses, to gauge the feasibility of this proposition. Both scenarios present a payback period of approximately 5 years, with a project lifespan extending to 25 years, signifying the practical feasibility of this initiative. The cost per Wp fluctuates between 300 HUF and 470 HUF, underscoring the economic viability of this venture. Despite being a landlocked country devoid of coastal regions, Hungary demonstrates immense potential to pioneer the establishment of a floating solar park. Remarkably, the nation is endowed with significant water bodies that can facilitate this innovation. For instance, Lake Balaton covers an area of 592 km², coupled with the river Tisza, which spans over 597 km² within Hungary, already accommodating two hydroelectric dams.

Additionally, the regions encompassing the River Danube and the River Hármas-Körös, which also features a dam, present viable sites for this endeavor. Lake Valence further augments the list of potential hosts for a floating solar park. Floating Solar is generally installed on existing hydropower or on the catchment area of dam, which is cost effective by using the existing transmission lines and distribution infrastructure and increases efficiency. For FPV in this project Tisza Dam has been considered. The Tisza Dam, located in Kisköre within Heves County, stands as a testament to the region's commitment to harnessing renewable energy. From 2000 to 2022, the average monthly electricity consumption in Heves County was recorded at 194.75 kWh[13]. This 2.5 MWp Floating Photovoltaic (FPV) park, capable of producing approximately 2,850,983 kWh annually (237,581kWh/monthly). From 2000 to 2022, the Tisza Dam in Kisköre, Heves County, witnessed an average monthly

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[12] Number of electric vehicle charging stations in Hungary from 2013 to 2021 https://www.statista.com/statistics/933078/number-of-electric-vehicle-charging-stations-in-hungary/ accessed 5 November 2023.

[13] Gas and electricity consumption by county and region. (2022). https://www.ksh.hu/stadat_files/kor/en/kor0068.html accessed 5 November 2023.

electricity consumption of 194.75 kWh. With the estimated annual energy output of this solar park, nearly 1,220 households within Heves County could be fully powered.

6.2 Energy Trend Forecasting in Next Two Decades

It is observed that the forthcoming two decades herald promising advancements in the renewable energy sector, with both combustible and non-combustible renewable sources witnessing growth. Solar energy and biomass are anticipated to play pivotal roles in energy extraction from renewable sources. Notably, towards the end of the projection period in 2041, solar energy is expected to see a significant surge compared to other renewable sources.

However, our ARIMA-driven predictions indicate that nuclear energy is poised to emerge as the dominant energy source in Hungary over the next two decades. While solar and other combustible renewable sources hold potential, they may not reach the prominence of nuclear energy. This bias towards nuclear energy is evident in the Hungarian government's recent initiatives, such as the establishment of Paks 2.

A critical observation from the study is Hungary's current energy independence. Till now Hungary has not been dependent, and this trend is expected to continue over the next two decades. By the end of our projection period in 2041, the dependency is estimated to be around 61%.

Given that Hungary is not particularly rich in fuel and raw material resources for energy production, it is imperative that the country leverages its internal potential. For instance, geothermal energy, which has so far contributed only 1-3% to the national gross energy consumption, presents an underutilized opportunity. Therefore, focusing on harnessing such indigenous resources could prove beneficial in fostering energy self-sufficiency and sustainability.

6.3 Energy Policy in Hungary

The Hungarian government has set ambitious goals for renewable energy, particularly focusing on solar power, in line with the country's increasing trend and potential. The government aims to achieve a solar power capacity of 6.5 GW by 2030 and 12 GW by 2040. These targets are supported by a study projecting even higher capacities: 8.554 GW by 2030 and 16.554 GW by 2040. In 2020, solar photovoltaic (PV) energy represented 7% of

Hungary's overall power composition, and this share is expected to grow significantly. The National Energy and Climate Plan aims for at least 20% of Hungary's total final gross energy consumption to come from renewable sources by 2030. The study's projection indicates a rise from 14% in 2022 to about 37% in 2030 and 39% by 2041. However, renewable energy consumption in the transportation sector is projected to decrease from 8.75% in 2022 to 7.77% in 2041. To address this, introducing PV systems in EV charging stations is suggested as a potential measure to meet the targets and shift the transportation sector towards renewable energy reliance.

6.4 Limitations

Emphasis on Solar Energy: The study clearly identifies both Solar and Geothermal energy as highly promising renewable energy sources for urban environments. However, while the research thoroughly explores solutions and models to augment solar energy utilization, it only conducts a broad analysis for geothermal energy without proposing specific models or solutions.

6.5 Future Work

Geothermal Energy Solutions: Subsequent research could delve deeper into the geothermal energy sector, devising and proposing specific models and solutions to harness its potential effectively within urban settings. This could involve developing strategies for tapping into geothermal sources and evaluating their feasibility and impact on urban energy consumption.

Summary

The research centers on the integration of renewable energy sources in urban areas of Hungary, pinpointing solar and geothermal as the most viable sources among the array of renewable options, including both combustible and non-combustible types. It presents three conceptual approaches for solar energy: model simulations, single-line diagram (SLD) designs, wiring configurations, and a comprehensive economic analysis that encompasses cost projections and financial modeling for various initiatives, such as EV Charging Station 1, EV Charging Station 2, and a Floating Solar Park. Further, the study extends to predict energy trends over the forthcoming two decades, concluding in 2041. This encompasses an analysis of future renewable energy production and consumption patterns, as well as an assessment of Hungary’s anticipated energy dependence by 2041. It delves into forecasting energy generation and consumption patterns of renewable sources as well as Hungary's energy self-sufficiency by the year 2041. In examining policy frameworks, the research concentrates on the current energy policies in Hungary, assessing their sufficiency in achieving the nation's renewable energy targets within the existing infrastructural landscape.

ABBREVIATION

AC	Alternating Current
AI	Artificial Intelligence
ARIMA	Autoregressive Integrated Moving Average
CUF	Capacity Utilization Factor
DC	Direct Current
DiffHor	Horizontal Diffuse Irradiation
EArray	Effective Energy at the Output of the Array
E_Grid	Energy Injected into Grid
EV	Electric Vehicle
FPV	Floating Photo Voltaic
GlobInc	Global Incident in coll. Plane
GlobEff	Effective Global, corr. for IAM and Shadings
GlobHor	Global Horizontal Irradiation
IRR	Internal Rate of Return
LC	Collection Loss
LS	System Loss
LCOE	Levelized Cost of Electricity
O&M	Operations and Maintenance (O&M) Cost
PV	Photo Voltaic
PR	Performance Ratio
PP	Payback Period
RES	Renewable Energy Sources
ROI	Return on Investment

STC	Standard Test Conditions
T_Amb	Ambient Temperature
YA	Array Yield
YR	Reference System Yield
YF	Final System Yield

APPENDIX A: CALCULATION FOR FINANCIAL MODEL OF EV CHARGING STATION-1, EV CHARGING STATION-2 & FLOATING SOLAR PARK

Calculation for EV Charging Station-1

Calculations

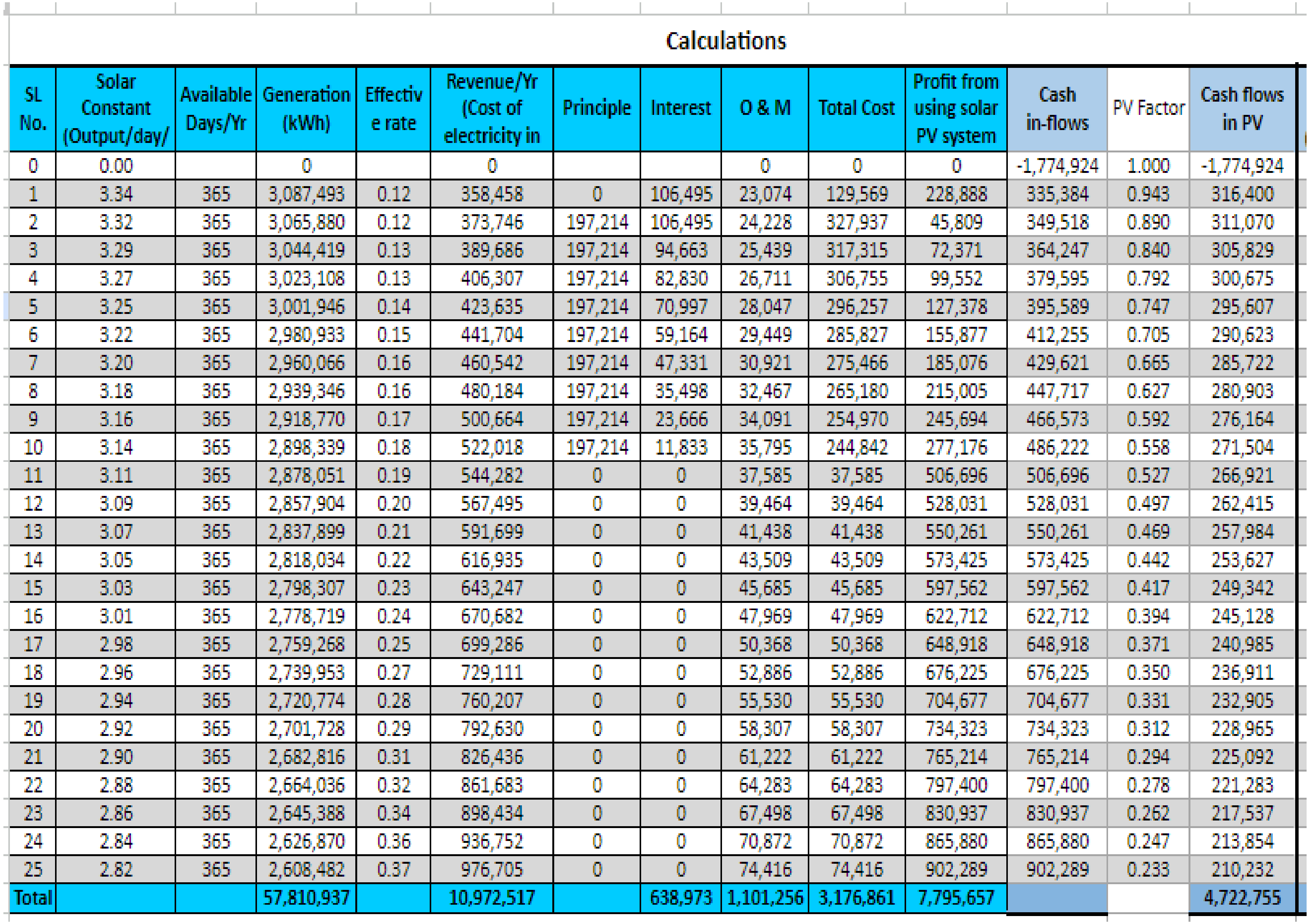
SL No.	Solar Constant (Output/day/	Available Days/Yr	Generation (kWh)	Effective rate	Revenue/Yr (Cost of electricity	Principle	Interest	O & M	Total Cost	Profit from using solar PV system	Cash in-flows	PV Factor	Cash flows in PV	Cummilative Cash-flows (-invest-O&
0	0.00		0		0			0	0	0	-46,521	1.000	-46,521	-46,521
1	3.34	365	71,878	0.12	8,345	0	2,791	605	3,396	4,949	7,740	0.943	7,302	-38,176
2	3.32	365	71,375	0.12	8,701	5,169	2,791	635	8,595	106	8,066	0.890	7,179	-29,475
3	3.29	365	70,875	0.13	9,072	5,169	2,481	667	8,317	755	8,405	0.840	7,057	-20,403
4	3.27	365	70,379	0.13	9,459	5,169	2,171	700	8,040	1,419	8,759	0.792	6,938	-10,944
5	3.25	365	69,887	0.14	9,862	5,169	1,861	735	7,765	2,097	9,127	0.747	6,820	-1,082
6	3.22	365	69,397	0.15	10,283	5,169	1,551	772	7,492	2,791	9,511	0.705	6,705	9,202
7	3.20	365	68,912	0.16	10,722	5,169	1,241	810	7,220	3,502	9,911	0.665	6,591	19,923
8	3.18	365	68,429	0.16	11,179	5,169	930	851	6,950	4,228	10,328	0.627	6,480	31,102
9	3.16	365	67,950	0.17	11,656	5,169	620	894	6,683	4,973	10,762	0.592	6,370	42,758
10	3.14	365	67,475	0.18	12,153	5,169	310	938	6,417	5,735	11,215	0.558	6,262	54,911
11	3.11	365	67,002	0.19	12,671	0	0	985	985	11,686	11,686	0.527	6,156	67,582
12	3.09	365	66,533	0.20	13,212	0	0	1,034	1,034	12,177	12,177	0.497	6,052	80,793
13	3.07	365	66,067	0.21	13,775	0	0	1,086	1,086	12,689	12,689	0.469	5,949	94,568
14	3.05	365	65,605	0.22	14,363	0	0	1,140	1,140	13,222	13,222	0.442	5,848	108,931
15	3.03	365	65,146	0.23	14,975	0	0	1,197	1,197	13,778	13,778	0.417	5,749	123,906
16	3.01	365	64,690	0.24	15,614	0	0	1,257	1,257	14,356	14,356	0.394	5,651	139,519
17	2.98	365	64,237	0.25	16,280	0	0	1,320	1,320	14,960	14,960	0.371	5,555	155,799
18	2.96	365	63,787	0.27	16,974	0	0	1,386	1,386	15,588	15,588	0.350	5,461	172,773
19	2.94	365	63,341	0.28	17,698	0	0	1,455	1,455	16,242	16,242	0.331	5,368	190,471
20	2.92	365	62,897	0.29	18,453	0	0	1,528	1,528	16,925	16,925	0.312	5,277	208,924
21	2.90	365	62,457	0.31	19,240	0	0	1,605	1,605	17,635	17,635	0.294	5,187	228,164
22	2.88	365	62,020	0.32	20,060	0	0	1,685	1,685	18,375	18,375	0.278	5,099	248,224
23	2.86	365	61,586	0.34	20,916	0	0	1,769	1,769	19,147	19,147	0.262	5,013	269,140
24	2.84	365	61,155	0.36	21,808	0	0	1,858	1,858	19,950	19,950	0.247	4,927	290,948
25	2.82	365	60,727	0.37	22,738	0	0	1,950	1,950	20,788	20,788	0.233	4,843	313,686
Tot			1,345,863		255,445		16,748	28,864	83,266	172,179			103,321	

Calculation for EV Charging Station-2

Calculations

SL No.	Solar Constant (Output/day/	Available Days/Yr	Generation (kWh)	Effective rate	Revenue/Yr (Cost of electricity in	Principle	Interest	O & M	Total Cost	Profit from using solar PV system	Cash in-flows	PV Factor	Cash flows in PV	Cummilative Cash-flows (-invest-O&M+Rev.)	
0	0.00		0		0			0	0	0	-38,062	1.000	-38,062	-38,062	
1	3.34	365	35,939	0.12	4,173	0	2,284	495	2,779	1,394	3,678	0.943	3,470	-33,889	
2	3.32	365	35,687	0.12	4,350	4,229	2,284	520	7,032	-2,682	3,831	0.890	3,410	-29,539	
3	3.29	365	35,438	0.13	4,536	4,229	2,030	546	6,805	-2,269	3,991	0.840	3,351	-25,003	
4	3.27	365	35,190	0.13	4,729	4,229	1,776	573	6,578	-1,849	4,157	0.792	3,292	-20,273	
5	3.25	365	34,943	0.14	4,931	4,229	1,522	601	6,353	-1,422	4,330	0.747	3,235	-15,342	
6	3.22	365	34,699	0.15	5,142	4,229	1,269	632	6,129	-988	4,510	0.705	3,179	-10,201	
7	3.20	365	34,456	0.16	5,361	4,229	1,015	663	5,907	-546	4,698	0.665	3,124	-4,840	
8	3.18	365	34,215	0.16	5,589	4,229	761	696	5,687	-97	4,893	0.627	3,070	750	
9	3.16	365	33,975	0.17	5,828	4,229	507	731	5,468	360	5,097	0.592	3,017	6,577	
10	3.14	365	33,737	0.18	6,076	4,229	254	768	5,250	826	5,309	0.558	2,964	12,654	
11	3.11	365	33,501	0.19	6,336	0	0	806	806	5,530	5,530	0.527	2,913	18,989	
12	3.09	365	33,267	0.20	6,606	0	0	846	846	5,759	5,759	0.497	2,862	25,595	
13	3.07	365	33,034	0.21	6,887	0	0	889	889	5,999	5,999	0.469	2,813	32,483	
14	3.05	365	32,803	0.22	7,181	0	0	933	933	6,248	6,248	0.442	2,764	39,664	
15	3.03	365	32,573	0.23	7,488	0	0	980	980	6,508	6,508	0.417	2,715	47,151	
16	3.01	365	32,345	0.24	7,807	0	0	1,029	1,029	6,778	6,778	0.394	2,668	54,958	
17	2.98	365	32,118	0.25	8,140	0	0	1,080	1,080	7,060	7,060	0.371	2,622	63,098	
18	2.96	365	31,894	0.27	8,487	0	0	1,134	1,134	7,353	7,353	0.350	2,576	71,585	
19	2.94	365	31,670	0.28	8,849	0	0	1,191	1,191	7,658	7,658	0.331	2,531	80,434	
20	2.92	365	31,449	0.29	9,226	0	0	1,250	1,250	7,976	7,976	0.312	2,487	89,660	
21	2.90	365	31,229	0.31	9,620	0	0	1,313	1,313	8,307	8,307	0.294	2,444	99,280	
22	2.88	365	31,010	0.32	10,030	0	0	1,379	1,379	8,652	8,652	0.278	2,401	109,310	
23	2.86	365	30,793	0.34	10,458	0	0	1,447	1,447	9,011	9,011	0.262	2,359	119,768	
24	2.84	365	30,577	0.36	10,904	0	0	1,520	1,520	9,384	9,384	0.247	2,318	130,672	
25	2.82	365	30,363	0.37	11,369	0	0	1,596	1,596	9,773	9,773	0.233	2,277	142,041	
Tota			672,932		127,722		13,702	23,616	68,126	59,597			32,799		

Calculation For Floating Solar Park



Calculations

SL No.	Solar Constant (Output/day/	Available Days/Yr	Generation (kWh)	Effective rate	Revenue/Yr (Cost of electricity in	Principle	Interest	O & M	Total Cost	Profit from using solar PV system	Cash in-flows	PV Factor	Cash flows in PV
0	0.00		0		0			0	0	0	-1,774,924	1.000	-1,774,924
1	3.34	365	3,087,493	0.12	358,458	0	106,495	23,074	129,569	228,888	335,384	0.943	316,400
2	3.32	365	3,065,880	0.12	373,746	197,214	106,495	24,228	327,937	45,809	349,518	0.890	311,070
3	3.29	365	3,044,419	0.13	389,686	197,214	94,663	25,439	317,315	72,371	364,247	0.840	305,829
4	3.27	365	3,023,108	0.13	406,307	197,214	82,830	26,711	306,755	99,552	379,595	0.792	300,675
5	3.25	365	3,001,946	0.14	423,635	197,214	70,997	28,047	296,257	127,378	395,589	0.747	295,607
6	3.22	365	2,980,933	0.15	441,704	197,214	59,164	29,449	285,827	155,877	412,255	0.705	290,623
7	3.20	365	2,960,066	0.16	460,542	197,214	47,331	30,921	275,466	185,076	429,621	0.665	285,722
8	3.18	365	2,939,346	0.16	480,184	197,214	35,498	32,467	265,180	215,005	447,717	0.627	280,903
9	3.16	365	2,918,770	0.17	500,664	197,214	23,666	34,091	254,970	245,694	466,573	0.592	276,164
10	3.14	365	2,898,339	0.18	522,018	197,214	11,833	35,795	244,842	277,176	486,222	0.558	271,504
11	3.11	365	2,878,051	0.19	544,282	0	0	37,585	37,585	506,696	506,696	0.527	266,921
12	3.09	365	2,857,904	0.20	567,495	0	0	39,464	39,464	528,031	528,031	0.497	262,415
13	3.07	365	2,837,899	0.21	591,699	0	0	41,438	41,438	550,261	550,261	0.469	257,984
14	3.05	365	2,818,034	0.22	616,935	0	0	43,509	43,509	573,425	573,425	0.442	253,627
15	3.03	365	2,798,307	0.23	643,247	0	0	45,685	45,685	597,562	597,562	0.417	249,342
16	3.01	365	2,778,719	0.24	670,682	0	0	47,969	47,969	622,712	622,712	0.394	245,128
17	2.98	365	2,759,268	0.25	699,286	0	0	50,368	50,368	648,918	648,918	0.371	240,985
18	2.96	365	2,739,953	0.27	729,111	0	0	52,886	52,886	676,225	676,225	0.350	236,911
19	2.94	365	2,720,774	0.28	760,207	0	0	55,530	55,530	704,677	704,677	0.331	232,905
20	2.92	365	2,701,728	0.29	792,630	0	0	58,307	58,307	734,323	734,323	0.312	228,965
21	2.90	365	2,682,816	0.31	826,436	0	0	61,222	61,222	765,214	765,214	0.294	225,092
22	2.88	365	2,664,036	0.32	861,683	0	0	64,283	64,283	797,400	797,400	0.278	221,283
23	2.86	365	2,645,388	0.34	898,434	0	0	67,498	67,498	830,937	830,937	0.262	217,537
24	2.84	365	2,626,870	0.36	936,752	0	0	70,872	70,872	865,880	865,880	0.247	213,854
25	2.82	365	2,608,482	0.37	976,705	0	0	74,416	74,416	902,289	902,289	0.233	210,232
Total			57,810,937		10,972,517		638,973	1,101,256	3,176,861	7,795,657			4,722,755

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