

American University Kyiv

Capstone Project:

**MANAGEMENT PRACTICES IN UKRAINE'S ENERGY SECTOR: PATHWAYS TO
ENHANCED ENERGY RESILIENCE**

**ПРАКТИКИ УПРАВЛІННЯ РОЗПОДІЛОМ ЕНЕРГІЇ В ЕНЕРГЕТИЧНОМУ
СЕКТОРІ УКРАЇНИ: ШЛЯХИ ДО ПІДВИЩЕННЯ ЕНЕРГЕТИЧНОЇ СТІЙКОСТІ**

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ABSTRACT

The transition towards decentralized energy systems has gained significant attention in recent years, particularly as the need for energy resilience increases due to geopolitical instability. This Capstone Project examines the potential of the UHEVsA (Ukraine, Home, Electric Vehicles, and Apartment) model as a solution to enhance energy security in Ukraine, particularly in scenarios where centralized energy infrastructure is compromised. The research focuses on the integration of renewable energy sources, such as solar panels and wind turbines, alongside energy storage systems and electric vehicles (EVs) as mobile energy banks. The project evaluates the technical feasibility, economic viability, and regulatory challenges of implementing UHEVsA at the household level, proposing strategies for its scalability and adaptability in urban and rural settings.

Key findings indicate that while the upfront investment for renewable energy systems, EVs, and energy storage is substantial, the long-term benefits—such as energy independence, lower operational costs, and resilience during power outages—make UHEVsA a promising alternative to traditional grid systems. The research also highlights several regulatory hurdles in Ukraine, including outdated policies that hinder the integration of decentralized energy systems and the adoption of electric vehicles. The study suggests that targeted policy updates, incentives for renewable energy adoption, and support for energy storage solutions are essential for the widespread implementation of the UHEVsA model.

Ultimately, this project presents a comprehensive analysis of UHEVsA's potential to stabilize Ukraine's energy supply during crises and its broader application as a sustainable energy solution for decentralized networks. Future research is recommended to focus on optimizing system integration, exploring alternative energy storage technologies, and assessing the social and economic impacts of decentralized energy solutions.

Keywords: UHEVsA, decentralized energy systems, renewable energy, energy security, electric vehicles, energy storage, solar panels, wind turbines, Ukraine

INTRODUCTION

This study examines the potential of distributed household generation from alternative energy sources, such as small-scale solar and wind power plants, to mitigate the risk of energy collapse in Ukraine and bolster national resilience. Ukraine's energy security has been severely compromised due to systematic attacks on its critical infrastructure, particularly power generation stations, distribution substations, and the national electrical grid. Since February 2022, Russian forces have destroyed and occupied approximately 35 GW of Ukraine's electricity generation capacity, which represented a substantial portion of the country's pre-war capacity of around 59 GW, as stated in the article from ETH Zurich (2024).

Consequently, Ukrainian citizens have faced recurring power outages, a situation that could escalate significantly during winter months when energy demands peak, and temperatures drop below zero. The destruction of centralized power sources has led to pressing concerns regarding the ability of urban areas to maintain functionality without reliable power. In scenarios where centralized power may be compromised for extended periods, distributed generation – primarily through small-scale renewable systems – presents a viable solution. Technologies such as solar panels, compact wind turbines, household inverters, lithium iron phosphate (LiFePO₄) storage systems, and electric vehicles capable of bidirectional energy transfer can enhance household self-sufficiency during outages. The Ukrainian government has responded by enacting measures to support the adoption of renewable energy, including waiving import duties on essential equipment and offering preferential loans for solar panel installations.

Investing in distributed energy generation is crucial for reducing the risk of future energy shortages while safeguarding against recurring disruptions. Comparing the costs of restoring centralized energy infrastructure to the investment required for household-based renewable systems illustrates the relative resilience and potential savings of a distributed generation approach.

Extensive research has explored the role of distributed generation and renewable energy sources in supporting centralized systems. Much of this literature focuses on integrating decentralized energy generation into existing grids to enhance grid resilience and stability. In contrast, the UHEVsA model aims to provide a primary source of energy when centralized systems fail or remain unavailable, similar to how water delivery trucks supply potable water during disruptions of centralized water systems.

Renewable and Efficient Electric Power Systems by G. M. Masters (2013) addresses the challenges of integrating solar, wind, and other renewable sources into existing grids. However, in the

context of UHEVsA, these insights inform how decentralized energy generation can function independently from central systems to ensure energy security. The UHEVsA model enables households and businesses to meet basic energy needs autonomously, particularly during crises. Similarly, *Electric Vehicle Integration into Modern Power Networks*, edited by R. Garcia-Valle and J. A. P. Lopes (2012), highlights the use of electric vehicles as mobile storage units contributing to grid stability. This work underscores the technical and economic challenges associated with EVs within centralized energy systems. While these studies provide foundational knowledge, they typically assume a stable centralized system onto which decentralized resources can be added. In contrast, this research examines the feasibility of utilizing distributed generation as a primary electricity supply system when centralized grids are destroyed or disabled for extended periods (a week or more). This approach addresses the need for resilience in scenarios where decentralized systems must function autonomously.

In Ukraine, legislation such as the Law of Ukraine “On Alternative Energy Sources” and the Law of Ukraine “On the Electricity Market” outline regulatory frameworks for renewable energy and energy efficiency. However, these regulations primarily target centralized systems and do not fully address scenarios requiring direct energy exchange among communities during prolonged outages.

Currently, many households possess energy storage systems with a capacity of up to 10 kW, which typically store energy during periods of supply availability and release it during outages. A limitation of such systems is their dependency on grid power for recharging, rendering them minimally effective during extended outages.

This research focuses on examining the feasibility and challenges of using distributed generation – primarily through the UHEVsA (Home-EVs-Apartment) approach – as a primary means of electricity supply during prolonged centralized grid failures. The model envisions suburban and rural households equipped with solar and wind power systems, storing energy for transport via electric vehicles (EVs) to urban centers. In cities, the energy could power offices and apartments directly, recharge residential storage systems, or be transferred to other EVs. High-rise buildings equipped with solar generation systems are also considered to contribute to urban energy self-sufficiency.

These approaches serve as the sole sources of energy generation and distribution in scenarios of severe centralized power system damage. Individuals would meet critical energy needs independently, sustaining a minimal level of self-sufficiency until centralized power is restored. Essential infrastructure, such as hospitals, large stores, and utilities, would continue operating with support from generators managed by local authorities. This strategy prevents a complete halt in national activity and

mitigates catastrophic consequences.

The study outlines steps for implementation, identifies vulnerabilities, and proposes recommendations for adjustments to legislation and regulatory frameworks. Necessary calculations and modeling will evaluate the feasibility of implementing the UHEVsA approach, beginning with projections of energy generation required to meet minimal consumption needs and determining the equipment (e.g., solar panels, wind turbines) required.

Further analysis will estimate the number of electric vehicles needed for energy transport to urban centers and assess energy storage capacity for effective distribution. An investment analysis will determine costs associated with the implementation, evaluating the state's ability to facilitate financing options, such as credit incentives. A comparison between investments in distributed generation and the costs of restoring centralized facilities highlights the relative resilience of decentralized systems. However, the vulnerability of centralized infrastructure to destruction remains a significant consideration, emphasizing the symbolic nature of such comparisons. A working model will demonstrate system operations, including requirements for a mobile application that tracks energy transactions, manages transfers, and facilitates payments. Additionally, recommendations will be provided for legislative and regulatory changes necessary to support the adoption of distributed energy systems and electric transport.

The Capstone Project structure begins with an introduction to the project's relevance, objectives, and the UHEVsA concept. A literature review distinguishes this approach by focusing on UHEVsA as a primary energy system rather than as support for centralized systems. The methodology section details data sources and analytical tools, including generation forecasts, equipment assessments, and investment modeling. The analysis evaluates energy storage, transport needs, and cost feasibility. A mobile application development section outlines tools for monitoring energy use, and the legal framework section identifies necessary regulatory adjustments. Conclusions summarize UHEVsA's viability as a primary energy source, with recommendations for future research.

CHAPTER 1. Literature review

The ongoing war in Ukraine has caused severe damage to the national energy infrastructure, making distributed energy systems increasingly vital for ensuring energy security. The UHEVsA (Home-EVs-Apartment) model, which integrates small-scale renewable energy sources (such as solar panels and wind turbines), energy storage systems (lithium-ion batteries), and electric vehicles (EVs), offers a promising solution to address the growing need for energy independence. The integration of these elements enables households and businesses to secure reliable energy supplies, even in times of crisis. To understand the technological, market, and regulatory challenges and opportunities associated with UHEVsA, it is essential to review existing academic literature and industry reports.

This literature review examines key themes related to distributed energy systems, the integration of electric vehicles (EVs) into energy networks, and the role of blockchain technology in facilitating energy transactions. Additionally, the financial viability and regulatory considerations of implementing the UHEVsA model in Ukraine are explored, given the unique political and economic challenges in the region.

In Ukraine, the destruction of the national electrical grid due to military actions has led to widespread power outages, particularly during peak demand seasons, such as the winter months. As central electricity systems become increasingly unreliable, there is an urgent need to implement alternative methods for households to meet their own energy needs. This is especially critical in scenarios where centralized electricity may not cover the domestic needs of the population at all, or it may be unavailable for prolonged periods. In such cases, the responsibility of the government will be to ensure critical infrastructure (such as water supply, sewage systems, hospitals, institutions etc.) is maintained. Businesses will also need to ensure their energy supply, while individuals will be expected to support their own needs, with government assistance in the form of financial incentives, tax reductions, and grants to foster the development of decentralized energy systems.

This idea is at the core of the UHEVsA (Home-EVs-Apartment) model. The model proposes a situation where every Ukrainian, whether they own or lease land or property, or are part of a cooperative or business with access to land or buildings, can install small-scale renewable energy systems – specifically, solar panels or household wind turbines (ranging from 0-10 kW). This would be made feasible through government support, international programs, or grants aimed at stimulating the development of decentralized electricity generation.

Given that a significant proportion of households with access to rooftops and land are located outside urban areas, it is anticipated that most of these small-scale generation stations will be installed

in suburban and rural regions. The majority of these installations will likely be on the roofs of buildings, which is why the "H" (Home) component of UHEVsA occupies a primary place in the model. Thus, households, apartment building associations (OSBB), businesses, and cooperatives will primarily generate energy for their own consumption.

The excess energy – i.e., when generation exceeds the household's immediate needs – will be stored in special storage systems, usually lithium iron phosphate (LiFePO₄) batteries. These storage units will be located directly at the same sites where the generation systems are installed, such as households, businesses, or apartment associations (OSBB). Additionally, part of the generated energy will be directed to charge electric vehicles (EVs), where "EV" stands for Electric Vehicle. If generation is unavailable due to a lack of sunlight or wind, the energy required to charge EVs can be sourced from the stored energy in batteries.

Once the EVs are fully charged, they will travel to cities, primarily for daily use, but also for energy distribution. In urban areas, EVs can directly supply power to apartments (A - Apartment) and offices. Additionally, EVs can transfer energy to other EVs or larger energy storage hubs. These hubs, in turn, can distribute energy to other EVs and portable charging stations, which can then supply power to more EVs, apartments, or charging stations. This creates a continuous energy exchange loop, allowing for flexible and efficient energy distribution between vehicles, hubs, and consumers.

Households and offices that do not have direct access to renewable energy generation will benefit from receiving electricity from the charged EVs, which will either transfer energy directly or recharge local storage systems. Typically, household storage systems in Ukraine range from 5 to 10 kWh, which, given the average monthly consumption of about 165 kWh per person (or approximately 5.5 kWh per day), could provide energy for 3-6 days. This calculation assumes average energy consumption, but during periods of more efficient use, this number could potentially be halved, providing energy for 6-12 days.

Given these considerations, this model necessitates the examination of various aspects related to energy generation, storage, and distribution. The overall aim is to assess how this decentralized system can ensure basic energy needs are met and how energy can be reliably distributed during periods when central power is unavailable.

1.1. Distributed Energy Systems and Integration with Renewable Energy Sources

Distributed energy systems, particularly those utilizing renewable sources such as solar and wind power, are central to the UHEVsA model. These systems offer the potential to mitigate energy

insecurity, particularly in regions with unreliable or compromised centralized grids, such as Ukraine. The following review examines key sources that address the integration of renewable energy systems into distributed power grids, their challenges, and solutions.

Ehrlich (2022), in *Renewable Energy: A First Course*, provides a foundational overview of renewable energy technologies, focusing on solar and wind power. The author outlines how these sources can be effectively integrated into small-scale household systems, which is directly relevant to the UHEVsA model. Ehrlich defines key concepts such as energy conversion efficiency, grid integration, and decentralized energy production. This work is beneficial for understanding the potential of renewable energy and the basic principles of integrating solar and wind energy into distributed systems. For the UHEVsA model, Ehrlich's insights can be directly applied to the "Home" component, where households generate their own energy using renewable sources. His discussion on grid integration is also relevant for ensuring that small-scale systems can interact with other decentralized energy sources or centralized grids when needed.

Agrawal and Soni (2021) in *Renewable Energy: Sources, Importance and Prospects for Sustainable Future* (published in *Crises, Challenges and Solutions*) provide a thorough overview of renewable energy sources, emphasizing their growing importance for a sustainable future. The authors explore the potential of solar, wind, and other renewable resources to reduce reliance on fossil fuels and enhance energy security. They also discuss key challenges such as the intermittent nature of renewable energy and the need for energy storage systems to stabilize supply. Their work aligns with the UHEVsA model's goals, as it highlights the importance of integrating renewable energy into decentralized systems. The authors' discussion on the feasibility and strategies for scaling small-scale renewable systems is directly applicable to the UHEVsA model, especially in addressing the need for efficient planning and deployment of energy generation in suburban and rural areas. Their focus on the importance of energy storage technologies, such as lithium-ion batteries, for ensuring energy security during low-generation periods is also highly relevant. For the UHEVsA model, which relies on local storage systems to balance energy supply and demand, Agrawal and Soni's insights can guide the selection of appropriate storage technologies and provide a broader understanding of their economic feasibility and impact. The authors emphasize how the implementation of renewable energy solutions can mitigate the challenges of traditional energy systems, such as grid instability and reliance on non-renewable resources, making their findings applicable to both the UHEVsA concept and broader energy transition strategies. In this context, Agrawal and Soni's work provides a robust framework for understanding the role of decentralized renewable energy systems in energy security, a critical aspect

for the UHEVsA model's success, especially in regions experiencing political and infrastructural instability.

Masters (2013), in *Renewable and Efficient Electric Power Systems*, explores renewable energy technologies and strategies for their integration into both existing and future power systems. Masters emphasizes the technical, economic, and environmental challenges of transitioning to renewable energy, including the integration of variable renewable energy sources like solar and wind. The book covers a variety of renewable technologies and provides a comprehensive analysis of how to incorporate them into efficient and reliable power grids. For the UHEVsA model, Masters' focus on distributed generation aligns with the model's emphasis on renewable energy sources like solar panels and wind turbines. The work offers a deep dive into the technical requirements and economic factors that must be considered for integrating renewable energy into decentralized systems. Masters also explores energy storage technologies and their role in stabilizing power systems, which is directly applicable to the UHEVsA model's reliance on local energy storage to ensure a steady supply during low renewable generation periods.

The works reviewed provide valuable insights into the integration of renewable energy and storage technologies within decentralized networks. These insights are directly applicable to the UHEVsA model, especially the "Home" component, where households rely on renewable energy sources like solar panels and wind turbines for their energy needs. The importance of energy storage technologies, as emphasized by Agrawal and Soni, is critical for ensuring stable and reliable energy supply, particularly during periods of low renewable energy generation.

For the UHEVsA model to fully replace centralized electricity supply in crisis situations, additional research, modeling, and design are needed to address specific challenges. Further exploration is required to adapt these systems to unstable conditions and ensure their scalability and effectiveness in regions with compromised infrastructure.

1.2. Integration of Electric Vehicles into Energy Systems

The integration of electric vehicles (EVs) into energy systems is a fundamental component of the UHEVsA model, where EVs serve not only as transportation devices but also as mobile energy storage units. This integration is particularly critical for regions like Ukraine, where the stability of the centralized electrical grid is compromised, and decentralized solutions are essential for energy security. Through technologies such as Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H), EVs can significantly contribute to energy distribution, especially during periods of high demand or when

centralized power is unavailable.

The book *Electric Vehicle Integration into Modern Power Networks*, edited by Garcia-Valle and Lopes (2012), provides an essential framework for understanding the integration of EVs into energy networks. This work examines how EVs, through V2G technology, can serve as both energy consumers and providers. The authors emphasize the flexibility and decentralization of power sources that V2G technology offers, which aligns well with the UHEVsA model's goal of establishing decentralized energy networks that rely on renewable energy and energy storage.

Garcia-Valle and Lopes (2012) focus on the role of EVs in transforming traditional energy systems. They explain how V2G technology allows EVs to provide a flexible and decentralized power source, reducing reliance on fossil fuels and enhancing grid stability. This is particularly relevant to the UHEVsA model, where EVs function as critical components of a decentralized, sustainable energy network. The ability of EVs to supply energy to the grid or to homes during periods of low renewable generation or high demand makes them an integral part of balancing energy supply and demand.

The challenges associated with the large-scale implementation of V2G are also discussed, including regulatory barriers, technical limitations, and the need for standardization in charging infrastructure, communication protocols, and regulatory frameworks. These considerations are vital for the UHEVsA model, which relies on the seamless integration of EVs into its decentralized energy system. To ensure reliable and efficient energy distribution, the UHEVsA model must be supported by a robust infrastructure and regulatory environment.

Following this, Noel et al. (2019), in their book *Vehicle-to-Grid: A Sociotechnical Transition Beyond Electric Mobility*, provide an in-depth exploration of V2G technology, focusing on its sociotechnical aspects and potential for large-scale adoption. They emphasize the transformative nature of V2G, which can enable EVs to act not only as energy consumers but also as providers of stored energy, thereby enhancing grid stability and reducing reliance on centralized systems. The book offers a comprehensive view of how V2G can create a more flexible and resilient energy network, aligning with the vision of the UHEVsA model.

Noel et al. (2019) also highlight the regulatory, technical, and social challenges that must be overcome to scale V2G technology. The authors argue for the development of standardized charging infrastructure and the creation of supportive regulatory frameworks to facilitate the seamless integration of V2G into existing energy networks. These insights are critical for the UHEVsA model, where EVs need to function autonomously in decentralized networks, especially in crisis situations where traditional centralized grids are unavailable or unstable.

Damiano et al. (2014), in *Vehicle-to-Grid Technology: State-of-the-Art and Future Scenarios*, further deepen the technological perspective on V2G, offering insights into the current state of the technology and its integration into decentralized systems. They explore key advancements in bidirectional charging systems, which enable seamless energy exchange between EVs, the grid, and local energy systems. This capability is central to the UHEVsA model, where EVs not only consume energy but also supply energy, particularly during times of low renewable generation or high demand.

Damiano et al. (2014) discuss the broader implications of V2G for grid stability, noting that EVs can provide a flexible and reliable energy source, which is crucial for maintaining stable energy supply in decentralized systems. Their work emphasizes the importance of bidirectional charging systems and the integration of EVs into the grid as both energy consumers and suppliers. This aligns directly with the UHEVsA model's goals of creating a decentralized, resilient, and flexible energy system that can operate independently during disruptions or crises.

The integration of EVs into energy systems through V2G and V2H technologies presents significant opportunities for enhancing energy resilience in decentralized networks. The works of Garcia-Valle and Lopes (2012), Noel et al. (2019), and Damiano et al. (2014) collectively highlight the potential of EVs to contribute to grid stability by acting as flexible storage units that can store and supply energy. While each work emphasizes different aspects of V2G technology, together they provide a comprehensive understanding of its potential to revolutionize energy systems, particularly in decentralized networks like the UHEVsA model. The challenges identified, such as the need for standardization, regulatory frameworks, and infrastructure development, are critical for the successful implementation of V2G in decentralized energy systems, and they align with the goals of the UHEVsA model to ensure reliable and efficient energy distribution in crisis situations.

1.3. Cryptocurrencies and Blockchain in Energy Transactions

The integration of blockchain technology in energy markets is an area of growing interest, particularly for decentralized systems like the UHEVsA model. Jiang et al. (2024), in their comprehensive survey *"Blockchain for Energy Market: A Comprehensive Survey"*, published as a preprint on *arXiv*, offer a thorough analysis of how blockchain technology is being applied in the energy sector. The paper examines the various use cases of blockchain in energy trading, power grid management, and the development of decentralized energy markets.

Jiang et al. (2024) explore the fundamental characteristics of blockchain that make it particularly suited to the energy market, including its ability to create a secure, transparent, and decentralized

ledger for energy transactions. One of the most important features highlighted in their survey is the role of blockchain in enabling peer-to-peer energy trading. This is highly relevant for the UHEVsA model, where households, businesses, and electric vehicles (EVs) exchange energy directly without the need for centralized intermediaries. The authors explain how blockchain can ensure that energy transactions are recorded immutably, providing participants with confidence in the accuracy and fairness of energy exchanges.

The paper also discusses the integration of blockchain with smart grid technologies, which is essential for modernizing energy distribution systems. Blockchain can enhance the capabilities of smart grids by ensuring secure and efficient management of energy flows between decentralized producers and consumers. For the UHEVsA model, this is particularly important, as it relies on a decentralized network where energy generated by solar panels or wind turbines can be exchanged between households, stored in batteries, or transferred to electric vehicles for later use. Blockchain helps ensure that these energy exchanges are tracked transparently and securely.

Jiang et al. (2024) also address the challenges of implementing blockchain in the energy sector, such as scalability, regulatory issues, and the integration of blockchain with existing energy infrastructure. The authors note that while blockchain has significant potential, its full-scale implementation will require overcoming technical and regulatory barriers. These insights are essential for the UHEVsA model, where regulatory frameworks and interoperability between various decentralized components must be carefully considered to ensure seamless integration.

Further expanding on the applications of blockchain in the renewable energy sector, Rejeb et al. (2024), in their study "*Blockchain technology in the renewable energy sector: A co-word analysis of academic discourse*", explore the trends and key themes in the academic literature surrounding blockchain's integration into the renewable energy market. The authors perform a co-word analysis, examining how blockchain has been discussed in the context of energy systems and identifying the most prominent topics and research areas.

Rejeb et al. (2024) find that the most common applications of blockchain in energy markets are related to decentralized energy trading, grid management, and the use of smart contracts to facilitate automated, secure, and transparent transactions. This is highly relevant to the UHEVsA model, where energy transactions between households, businesses, and electric vehicles (EVs) must be secure and transparent. Blockchain can streamline these transactions by providing a decentralized ledger that ensures accountability without relying on traditional intermediaries.

The study also highlights the growing interest in integrating blockchain with renewable energy

systems, particularly in terms of improving the efficiency of distributed energy networks. Blockchain can help manage complex energy flows, ensuring that energy generated from renewable sources such as solar or wind is efficiently distributed and stored across different participants in the network. For the UHEVsA model, this can be crucial, as it relies on decentralized, small-scale renewable generation sources, where energy needs to be tracked and exchanged securely.

In addition, Rejeb et al. (2024) discuss the challenges and barriers to implementing blockchain in energy systems, including regulatory concerns, scalability, and the technical infrastructure required to support large-scale blockchain applications. These issues must be addressed for blockchain to be fully integrated into decentralized energy systems like UHEVsA, which is designed to operate efficiently in regions with compromised infrastructure or during crises when traditional centralized systems are unavailable.

However, both studies acknowledge the technical and regulatory challenges that must be addressed for blockchain to achieve its full potential in energy systems. These challenges, including scalability, regulatory frameworks, and infrastructure integration, are essential considerations for the UHEVsA model as it seeks to implement blockchain in real-world applications. Continued research and innovation are needed to overcome these barriers and fully harness blockchain's potential in creating more resilient, efficient, and transparent energy systems.

1.4. Energy Management Technologies in Distributed Networks

Energy management technologies (EMTs) are integral to ensuring the efficient operation of distributed energy systems, especially in decentralized models such as UHEVsA. These technologies help optimize energy production, storage, and consumption across distributed networks, ensuring that energy flows are balanced and stable. In this section, we review three key publications that discuss critical energy management technologies in distributed networks: Distributed Energy Resource Management Systems (DERMS), Energy Management Systems (EMS), and the integration of Electric Vehicles (EVs) with Information and Communication Technologies (ICT).

The paper by Strezoski (2020), titled *"Distributed Energy Resource Management Systems – DERMS: State of the Art and How to Move Forward"*, provides an extensive review of Distributed Energy Resource Management Systems (DERMS), which are essential for managing the complexities of decentralized energy networks. DERMS enable the integration and coordination of various energy resources such as solar panels, wind turbines, and energy storage systems into a unified, flexible, and efficient network. Strezoski explores the current state of DERMS and outlines the key technologies

that support their implementation, such as advanced forecasting tools, real-time monitoring systems, and optimization algorithms. One of the key insights from this paper is the importance of integrating DERMS with grid management technologies to ensure that energy flows between distributed resources and the grid are optimized. For the UHEVsA model, DERMS could be employed to effectively manage energy exchanges between households, businesses, and electric vehicles (EVs), ensuring that surplus energy is either stored in batteries or transferred to other participants in the system. This will be crucial for maintaining stability and efficiency, especially when renewable generation is intermittent. Strezoski also highlights the challenges associated with scaling DERMS for broader applications, including issues of data management, regulatory constraints, and interoperability with existing grid infrastructure. These challenges must be addressed for systems like UHEVsA to function optimally, particularly in regions where grid infrastructure is less reliable or compromised.

Marini, Mortazavi, Piegari, and Ghazizadeh (2018) in *"An Efficient Graph-Based Power Flow Algorithm for Electrical Distribution Systems with a Comprehensive Modeling of Distributed Generations"* present a method for efficiently modeling power flow in electrical distribution systems that integrate distributed energy resources (DERs). Their approach uses a graph-based algorithm to optimize the distribution of energy in systems with significant integration of renewable energy sources such as solar and wind. This method allows for the efficient modeling of power flow in complex, decentralized grids, which is critical for the UHEVsA model where energy is generated, stored, and distributed across multiple decentralized units, such as households, businesses, and electric vehicles (EVs).

The algorithm proposed by Marini et al. is valuable for UHEVsA as it helps ensure the stability and reliability of energy distribution across systems that rely heavily on renewable sources, which are often intermittent. The integration of distributed energy generation, energy storage, and EVs as mobile energy sources requires sophisticated models to ensure energy flows are balanced and efficient, especially during periods of low renewable generation or high demand. This paper offers an effective tool for assessing the efficiency and feasibility of such integration, providing insights that can guide the design and optimization of the UHEVsA model.

In addition to its technical contributions, the paper highlights the importance of modeling energy distribution in real-time, considering factors such as energy supply reliability and economic evaluation. These factors are crucial for UHEVsA, where energy security and economic feasibility are central to ensuring that decentralized systems can function effectively, particularly in crisis situations.

The book *"Design and Analysis of Distributed Energy Management Systems"*, edited by Tatsuya

Suzuki, Shinkichi Inagaki, Yoshihiko Suzuki, and Anh Tuan Tran, offers a comprehensive look into Energy Management Systems (EMS) and their integration with Electric Vehicles (EVs) and Information and Communication Technologies (ICT). This resource explores the technical and operational aspects of EMS, which are responsible for optimizing the generation, storage, and consumption of energy within decentralized networks. The editors emphasize the importance of EMS in coordinating energy flows between distributed energy sources, storage systems, and end-users. Through the integration of EMS, renewable energy resources can be effectively utilized, ensuring that energy is available when needed while minimizing waste. For the UHEVsA model, EMS would enable seamless communication and energy management between different components of the system, such as solar panels, EVs, and batteries. These systems allow for optimal dispatching of energy, ensuring that EVs are charged efficiently and excess energy is stored for later use. Moreover, the book explores how EVs, integrated with ICT, can play a pivotal role in the decentralization of energy systems. By using V2G (Vehicle-to-Grid) and V2H (Vehicle-to-Home) technologies, EVs can act as mobile storage units that contribute to grid stability and provide backup power during periods of high demand or low generation. This integration allows for a more flexible and resilient energy system, essential for the success of the UHEVsA model.

In the article *"Integration of Electric Vehicle into Smart Grid: A Meta Heuristic Algorithm for Energy Management Between V2G and G2V"* by Srihari et al. (2024), the authors present a meta-heuristic algorithm to optimize energy management between Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) configurations. This study explores the integration of Electric Vehicles (EVs) into smart grid systems, which is crucial for managing energy exchanges between EVs and the grid or homes. The meta-heuristic algorithm proposed by the authors aims to optimize the charging and discharging processes of EVs, enhancing the stability and efficiency of smart grids. By utilizing both V2G and G2V technologies, EVs can either supply energy to the grid or store energy from it, depending on the needs of the system. This flexibility is essential for decentralized systems like UHEVsA, where energy generated from renewable sources must be stored and redistributed efficiently. The authors emphasize the role of ICT in facilitating communication between EVs, smart grids, and other energy management systems, ensuring seamless energy exchanges and optimal system performance. This paper provides a valuable perspective on how EVs, integrated with ICT, can contribute to decentralized energy systems by acting as mobile storage units that improve grid stability and resilience.

Energy management technologies such as DERMS, EMS, and the integration of EVs with ICT are

essential for the effective functioning of decentralized energy systems like UHEVsA. These technologies enable efficient energy management by optimizing energy flows, improving grid flexibility, and ensuring the stability of distributed networks. The integration of DERMS allows for the seamless coordination of distributed energy resources, ensuring efficient energy production and consumption. EMS help optimize energy storage and distribution, ensuring that renewable energy is effectively utilized. Meanwhile, the integration of EVs with ICT provides additional flexibility by allowing EVs to act as mobile storage units, contributing to grid stability during periods of high demand or low generation. Continued development and research into these technologies are necessary to overcome the challenges associated with scaling and implementing decentralized energy systems.

1.5. Regulatory Aspects and Economic Models for Renewable Energy

The successful implementation of the UHEVsA model depends not only on technological innovations but also on understanding the regulatory and economic frameworks that govern renewable energy systems. These frameworks are crucial for creating an environment conducive to decentralized energy solutions, such as small-scale renewable systems, electric vehicles, and energy storage units. This section reviews key literature that provides insight into the regulatory and economic considerations for renewable energy, with a specific focus on their application in Ukraine, where both geopolitical and economic factors play a significant role in shaping energy markets.

El-Shimy's (2018) article, "Economics of Variable Renewable Sources for Electric Power Production", examines the economic challenges associated with the integration of variable renewable energy sources, such as wind and solar, into power grids. The paper discusses the variability of these energy sources and their implications for electricity markets, grid stability, and power pricing. One of the key insights from the study is the importance of managing the intermittency of renewable energy generation. The economic models proposed by El-Shimy focus on the need for cost-efficient storage solutions and backup systems to mitigate the impact of variable renewable generation on grid operations.

El-Shimy highlights several economic strategies, including demand-side management, dynamic pricing, and the development of energy storage systems, which can help stabilize grids and ensure reliable energy supply. These strategies are essential for decentralized systems like UHEVsA, which rely on renewable energy sources that can fluctuate throughout the day. In the context of UHEVsA, managing the variability of solar and wind energy through energy storage, such as lithium-ion batteries, will be crucial to ensuring consistent power supply and maintaining economic viability.

Additionally, the integration of variable renewable sources into electricity markets requires supportive regulatory frameworks, such as incentives for renewable energy adoption and policies that encourage energy storage investments.

The paper by Barcellona et al. (2017), "Economic Viability for Residential Battery Storage Systems in Grid-Connected PV Plants", explores the financial aspects of integrating residential battery storage systems with grid-connected solar photovoltaic (PV) installations. This study is highly relevant for decentralized energy systems, such as UHEVsA, which aim to store excess energy generated by solar panels for later use. The authors focus on the economic feasibility of battery storage in the residential sector, considering factors such as system costs, electricity tariffs, and available financial incentives.

The paper's findings emphasize that the economic viability of battery storage in residential PV plants depends on several factors, including local electricity prices, the availability of net metering, and the capital cost of battery systems. In regions with high electricity tariffs or limited access to grid electricity, the economic benefits of installing a residential battery storage system are more pronounced. For the UHEVsA model, this work highlights the importance of incorporating energy storage solutions to optimize the use of locally generated renewable energy, ensuring that excess energy is available during periods of high demand or low renewable generation. Furthermore, the study underscores the role of policy incentives, such as subsidies or tax reductions, in making residential storage systems economically viable for households.

Both El-Shimy (2018) and Barcellona et al. (2017) provide critical insights into the economic aspects of renewable energy integration, focusing on the challenges of managing variability and optimizing the use of energy storage. The integration of variable renewable energy sources, such as solar and wind, into decentralized systems like UHEVsA requires careful economic planning, including the use of energy storage solutions to ensure reliability and stability. Additionally, regulatory frameworks that support the adoption of renewable energy and energy storage systems, such as financial incentives and net metering policies, are crucial for ensuring the long-term economic viability of these systems. For UHEVsA, these economic models offer valuable strategies for managing energy flows, optimizing renewable generation, and improving overall system efficiency. As renewable energy markets evolve, continued research and innovation in energy storage, regulatory policies, and economic models will be key to unlocking the full potential of decentralized energy systems.

Regulatory Framework of Ukraine

In Ukraine, the deployment of decentralized energy systems is governed by a set of laws and regulations that provide the legal foundation for renewable energy development and energy market operation. Key laws in this area include:

- Law of Ukraine "On Alternative Energy Sources" – This law establishes the principles and incentives for renewable energy development, including the green tariff mechanism, which provides financial support to producers of renewable energy. The law aims to promote the use of renewable sources such as solar, wind, and biomass to reduce dependence on traditional energy sources.
- Law of Ukraine "On the Electricity Market" – This law sets the rules for electricity market operation, aiming to promote competition, transparency, and market liberalization. It provides a framework for electricity trading and establishes rules for integrating renewable energy into the grid.
- Law of Ukraine "On Energy Efficiency" – This law provides guidelines for improving energy consumption practices across various sectors, including residential, industrial, and transport. It includes provisions for improving energy efficiency in public buildings, energy auditing, and incentivizing energy-saving technologies.
- Law of Ukraine "On the National Energy and Utilities Regulatory Commission" – This law defines the powers and responsibilities of the National Energy and Utilities Regulatory Commission (NEURC), which regulates energy markets, sets tariffs, and ensures fair competition in the energy sector.

Understanding the legal landscape is essential for implementing decentralized energy systems in Ukraine. The current laws and regulations provide a foundation for integrating renewable energy into the national grid, promoting energy efficiency, and supporting investment in alternative energy technologies. However, these laws may need revisions to better accommodate decentralized energy solutions, such as microgrids and the integration of electric vehicles as mobile storage units. Ensuring that the regulatory framework is adaptive and supportive of such innovations is vital for enhancing the resilience and stability of Ukraine's energy system, especially considering the ongoing geopolitical challenges.

These laws assume that a well-regulated energy market, supported by appropriate policies, is crucial for the successful integration of renewable energy sources and the transition to a more sustainable and decentralized energy system. However, as Ukraine's energy sector faces new challenges, especially from geopolitical instability, continuous adaptation of these laws is required to

accommodate new technologies and business models, such as decentralized generation and smart grid solutions.

The legal framework in Ukraine supports renewable energy deployment but needs continuous adjustments to enable the integration of new technologies. This is particularly true for decentralized energy solutions, such as microgrids and smart grids, which require regulatory structures that can accommodate innovations. Ensuring that the legal framework remains flexible and responsive is crucial for enhancing the resilience and sustainability of the energy system.

A robust, adaptive regulatory environment is essential for enabling the widespread adoption of decentralized energy solutions. As Ukraine seeks to enhance its energy resilience and independence, particularly in the face of geopolitical threats, a flexible and well-supported legal framework will be key to supporting the UHEVsA model and ensuring the efficient deployment of decentralized energy systems.

The selected works provide a comprehensive foundation for studying the regulatory and economic aspects of renewable energy and decentralized energy systems. They cover both theoretical frameworks and practical applications essential for integrating renewable energy into decentralized networks. However, further research is needed to refine regulatory frameworks to ensure they can support emerging technologies and business models. Understanding these regulatory foundations is critical for identifying potential gaps and areas for improvement in Ukraine's regulatory environment, ultimately enabling the widespread adoption of decentralized energy solutions in the context of the UHEVsA model.

CHAPTER 2. Methodology

2.1. Data Sources

Data on the potential generation capacity of solar and wind energy will be collected from meteorological studies, energy research organizations, and government reports. These forecasts will help predict the amount of energy available from renewable sources based on location, seasonal variations, and expected system efficiency. For example, data from the *Energy Potential Atlas of Renewable Energy Sources in Ukraine* (Kudria, 2020) will be used to estimate the wind and solar energy potential in different regions.

To assess the potential of wind and solar energy in Ukraine, data on the distribution of total solar radiation and wind speed across the country will be used. The following graphs illustrate these parameters, which help forecast the available energy from renewable sources.

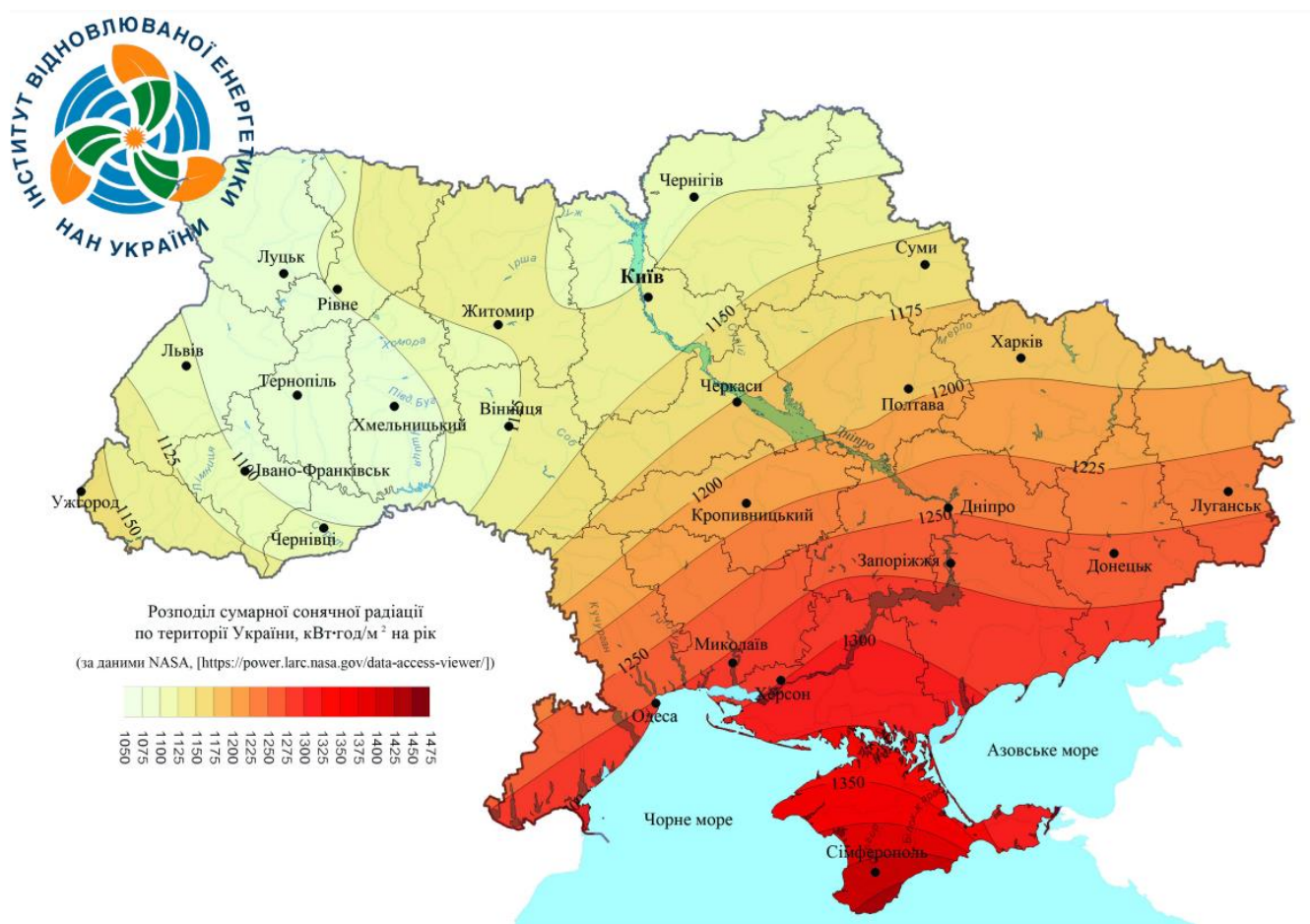


Figure 2.1.1. Distribution of total solar radiation across Ukraine (Source: Energy Potential Atlas of Renewable Energy Sources in Ukraine, Kudria, 2020).

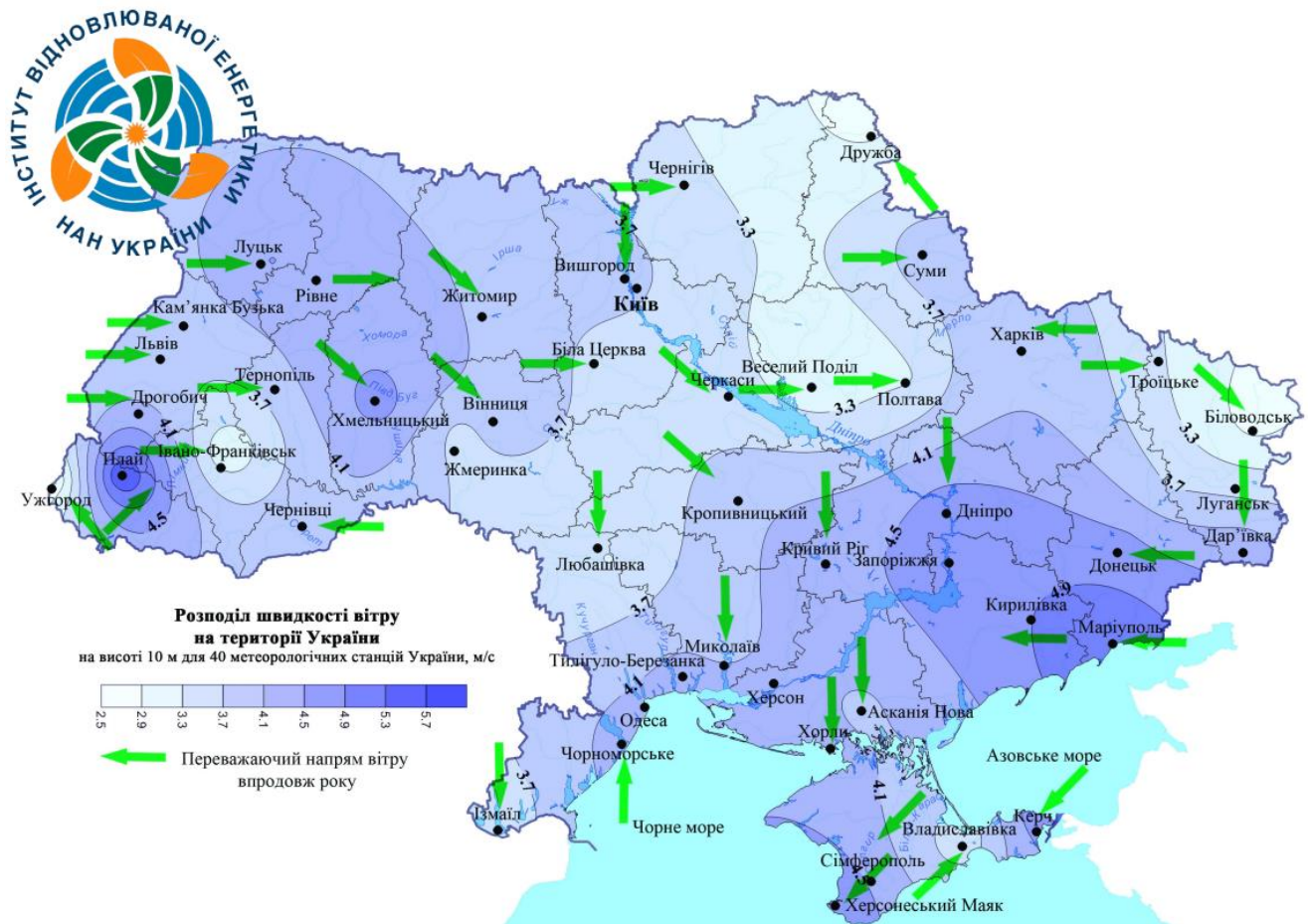


Figure 2.1.2. Distribution of wind speed across Ukraine (Source: Energy Potential Atlas of Renewable Energy Sources in Ukraine, Kudria, 2020).

The performance of energy storage systems (e.g., lithium-ion batteries) will also be based on technical specifications and real-world data from manufacturers and market reports. For example, data from Tesla's Powerwall and BYD will be referenced to evaluate storage capacity and performance, alongside industry reports from Bloomberg New Energy Finance (BNEF) on the development of storage technologies.

Data on the energy consumption patterns of Ukrainian households and businesses will be used to model the energy needs of the UHEVsA system. This data will be sourced from national energy consumption statistics from the State Statistics Service of Ukraine, utility companies such as Kyivenergo, and government sources such as the Ministry of Energy of Ukraine (2020).

Demand estimates will consider typical household energy use, business energy consumption, and

electric vehicle (EV) charging requirements, accounting for daily and seasonal fluctuations. Reports from International Energy Agency (IEA) and Ukrenergo will provide necessary data to assess energy use and EV charging patterns.

Data on the capital and operational costs of installing and maintaining renewable energy systems (solar panels, wind turbines), energy storage units, and electric vehicles will be gathered from industry reports, manufacturers, and market research. For instance, cost data from SolarWorld and Siemens Gamesa will inform solar and wind turbine installation costs, while information on energy storage costs will be based on reports from BNEF and Wood Mackenzie.

The cost analysis will include both initial installation costs and ongoing operational expenses, including maintenance and possible government incentives or subsidies for renewable energy adoption. Relevant government data and financial incentives from the Ukrainian State Fund for Energy Efficiency (2020) will also be considered in this analysis.

2.2. Analytical Approaches

In this section, various analytical approaches will be employed to evaluate the performance and feasibility of the UHEVsA system. These methods will focus on energy flow simulations, cost-benefit analysis, scenario forecasting, and optimization techniques to assess how the system performs under different conditions.

Energy flow simulations will model the interactions between different components of the UHEVsA system, including renewable energy sources (solar panels and wind turbines), energy storage units, electric vehicles, and households. These simulations will account for factors such as energy generation, storage, consumption, and distribution, providing insights into the system's dynamic performance. The simulations will be run under various scenarios to evaluate the system's performance during peak demand, low renewable generation, and crisis situations where centralized grids are unavailable.

A cost-benefit analysis will be conducted to assess the economic feasibility of implementing the UHEVsA system. This analysis will compare the total costs of the decentralized energy system, including installation, maintenance, and energy storage, against the anticipated benefits, such as energy savings, improved energy security, and potential revenue from energy sharing. It will also compare the costs of UHEVsA with those of restoring and maintaining centralized infrastructure, considering both short-term and long-term economic factors.

Scenario forecasting will be applied to predict future energy demand and generation capacity

under different conditions, such as fluctuating energy consumption, availability of renewable resources, and technological advancements. These forecasts will inform decisions regarding the scale and infrastructure requirements for the UHEVsA system, helping to estimate the potential return on investment over time.

Optimization models will be used to find the most efficient allocation of resources in the UHEVsA system. These models will aim to determine the optimal distribution of energy between the different components of the system, such as solar panels, wind turbines, batteries, and electric vehicles. Optimization techniques, including linear programming and mixed-integer optimization, will be used to identify configurations that minimize costs while ensuring a reliable and efficient energy supply for households and businesses.

This comprehensive approach will enable a detailed analysis of the UHEVsA system's performance, identifying areas for improvement and helping to ensure that the system operates efficiently and economically in real-world conditions.

2.3. Generation Forecasts and Equipment Volume Assessment

Forecasting techniques will be employed to estimate the generation potential of solar and wind energy, taking into account various factors such as geographical location, weather conditions, and seasonal fluctuations. Historical data on renewable energy production from regions with similar climatic conditions to Ukraine will be analyzed to estimate the energy generation potential across different seasons. In addition, specific models will be applied to simulate energy availability based on different weather conditions (e.g., sunny vs. cloudy days, varying wind speeds) and how they impact renewable energy generation over time.

Based on these forecasts and demand estimates, the necessary volume of equipment (solar panels, wind turbines, energy storage units, EVs) will be determined to meet the energy needs of households and businesses. The analysis will factor in the efficiency and generation/storage capacity of each component, considering the specific energy requirements of households, including daily energy consumption and seasonal variations.

CHAPTER 3. RESULTS

3.1 Analysis of UHEVsA as a Primary Power Supply System

3.1.1 Equipment and Energy Storage Requirements

According to the Energy Potential Atlas of Renewable Energy Sources in Ukraine (Kudria, 2020), scientific research indicates that the theoretical installed capacity for solar energy systems (SES) is 82,768 MW, and the total potential capacity for wind energy systems (WES) is 688,000 MW. While these figures exceed Ukraine's own energy needs (22,000 MW) by a factor of 4 to 30, as stated in the article from ETH Zurich (2024), it should be noted that potential generation data alone is insufficient to evaluate the feasibility of replacing centralized electricity supply with the UHEVsA (Home, Electric Vehicles, Apartment) model for meeting household energy needs in the short term. This is primarily due to the fact that when estimating potential, it is considered without the constraints imposed by the UHEVsA model, where generation is exclusively provided by the population rather than by commercial or state-owned power stations. Therefore, additional calculations will be carried out to assess the ability of households (the population) to generate electricity.

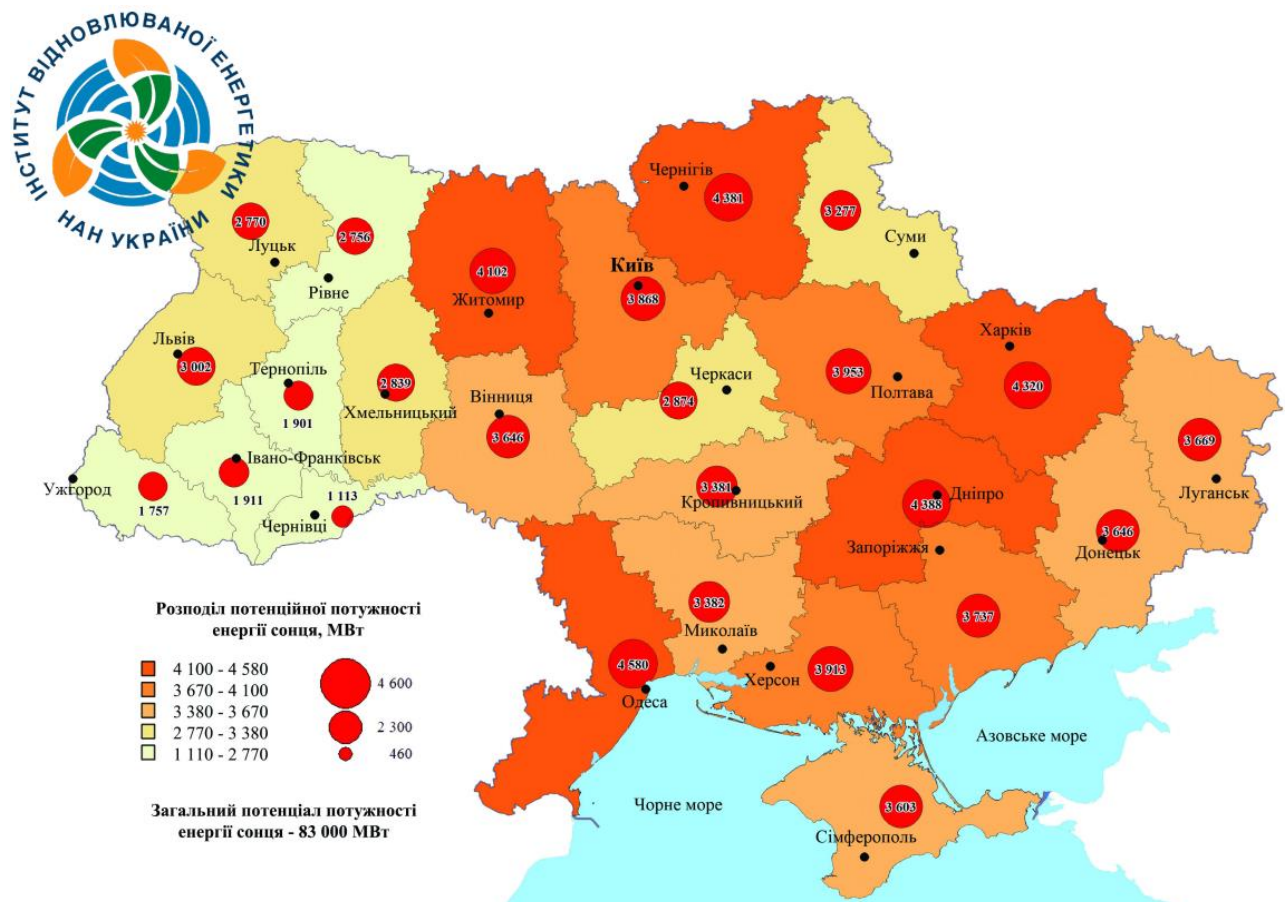


Figure 3.1.1.1 General Solar Energy Potential Capacity in Ukraine (Kudria, 2020)

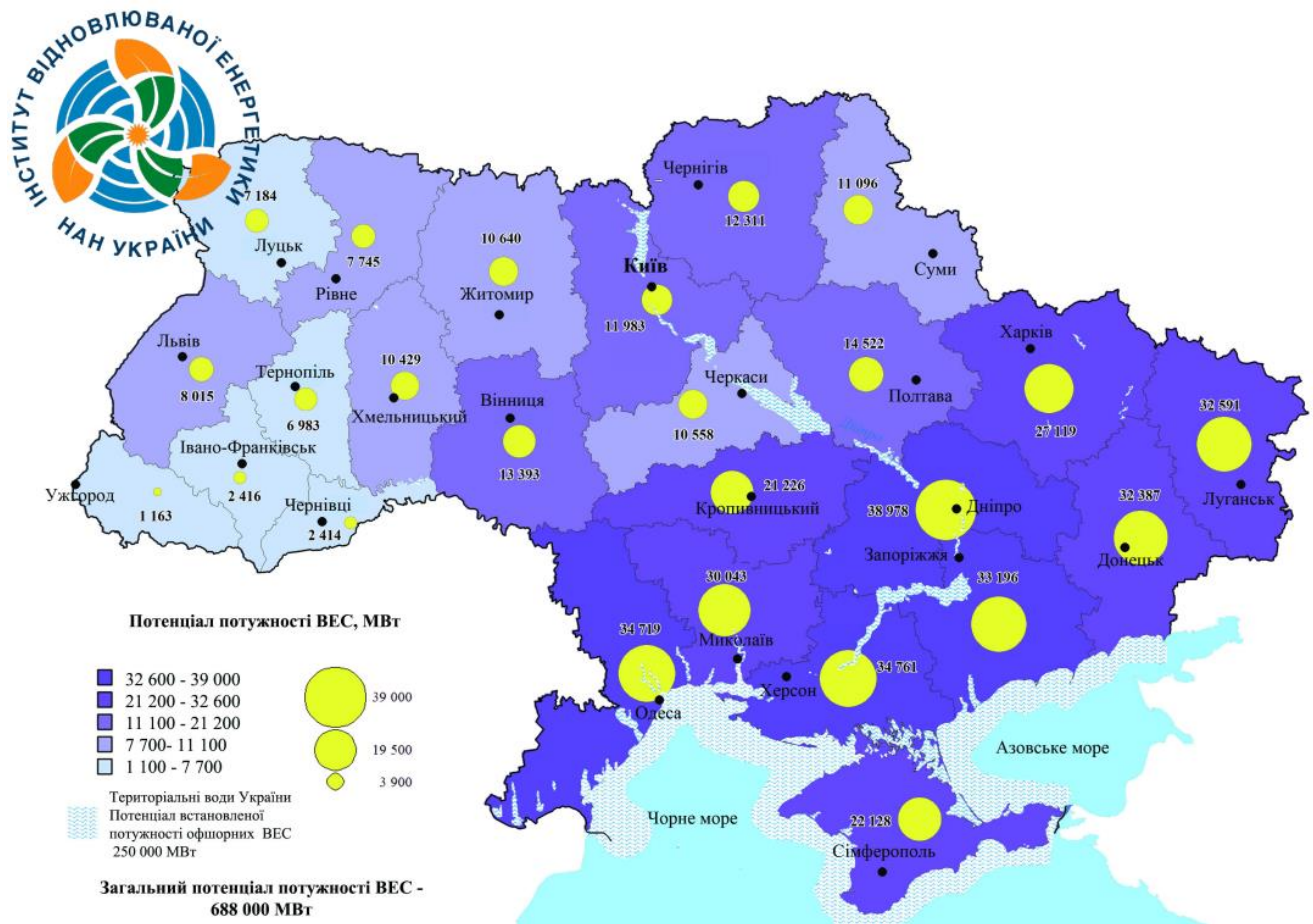


Figure 3.1.1.2. General Wind Energy Potential Capacity in Ukraine (Kudria, 2020)

This section outlines a stepwise approach to determining the optimal configuration of energy generation systems for the UHEVsA model in a typical household. Initially, calculations are based on the estimated daily energy demand required to support the household, fully charge a personal electric vehicle during the night, and charge a guests’ vehicle during the day time. This baseline demand serves as a foundation for defining the sufficient generation capacity needed to ensure UHEVsA's functionality.

Subsequently, a physical capacity approach is employed to evaluate the maximum generation capabilities of an average household with a medium-sized house and a 400-600 m² land area. This calculation assumes the available rooftop and free land space about 100m² are used to install solar panels and wind turbines, enabling maximum energy production under optimal conditions.

Finally, the combined approach integrates elements of the previous two methods. By

incorporating physical limitations while ensuring sufficient generation for baseline demand, this method adjusts the energy system design to bridge the gap between theoretical and practical constraints. Through this progression, the UHEVsA model achieves a balanced, realistic energy generation system tailored to meet both household needs and environmental conditions.

1. Practical Energy Balancing Approach

The approach to determining the necessary equipment for meeting household energy needs is based on practical energy balancing, taking into account the technical characteristics of standard residential chargers with a power rating of 7 kW. These chargers can deliver up to 7 kW of power per hour, allowing for theoretical charging of 168 kWh over 24 hours of continuous operation. The energy management system is designed to distribute charging times efficiently. Guest vehicles are charged during the day, while household owners' vehicles are charged overnight. This schedule ensures optimal use of the charging infrastructure while balancing energy consumption throughout the day.

In our model, we assume that the battery capacity of a single electric vehicle is 55 kWh. Additionally, we account for energy losses in both the household system and the vehicle during charging, which we estimate at 30%. To meet the daily energy requirements of the household, including 10 kWh for basic needs such as lighting, appliances, and heating, as well as charging two electric vehicles (one belonging to the household and one guest vehicle), the total energy generation needed is calculated as:

$$(10\text{kWh/day}+55\text{kWh/day}+55\text{kWh/day})/0.7=171.4\text{ kWh/day}$$

For simplicity, this value is rounded to 170 kWh per day.

To manage short-term surpluses and deficits in electricity generation, energy storage systems with a capacity of 100 kWh are integrated into the system. These storage units are charged alongside the vehicles during both day and night, supplementing the energy supplied by solar and wind installations.

This approach provides a realistic framework for integrating renewable energy sources, storage systems, and charging infrastructure into a household's energy management system. It reflects a balanced and sustainable solution for managing both stationary and mobile energy consumption.

This calculation shows that the household needs to generate 170 kWh per day to meet its own consumption and charge electric vehicles.

To meet this 170 kWh requirement, we will calculate the necessary number of solar panels and wind turbines that must be installed in the household.

The following calculations break down the energy generation by wind (1 wind turbine 5 kW) and solar systems, considering seasonal differences in energy availability, and calculate the required

number of solar panels to cover any remaining energy demand.

Winter:

1. Wind Generation: The wind turbine's efficiency in winter is estimated at 0.6. Therefore, the daily generation from a 5 kW wind turbine is: $5 \text{ kW} \times 0.6 \times 24 \text{ hours} = 72 \text{ kWh}$
2. Remaining Energy Demand: The total required energy is 170 kWh/day. Subtracting the wind turbine's generation: $170 \text{ kWh} - 72 \text{ kWh} = 98 \text{ kWh}$
3. Solar Panel Calculation: The daily solar panel generation in winter is assumed to be 1 nominal of the whole station. Therefore, to cover the remaining 98 kWh/day: $98 \text{ kWh} / 0.4 \text{ kW} = 245 \text{ panels}$
4. Nominal Power: $245 \text{ panels} \times 0.4 \text{ kW} = 98 \text{ kW}$
5. Total Area for Panels: $245 \text{ panels} \times 1.87 \text{ m}^2 = 458 \text{ m}^2$

Autumn:

1. Wind Generation: In autumn, the wind turbine's efficiency is 0.5. Therefore, the daily generation from a 5 kW wind turbine is: $5 \text{ kW} \times 0.5 \times 24 \text{ hours} = 60 \text{ kWh/day}$
2. Remaining Energy Demand: The total required energy is 170 kWh/day. Subtracting the wind turbine's generation: $170 \text{ kWh} - 60 \text{ kWh} = 110 \text{ kWh}$
3. Solar Panel Calculation: The daily solar panel generation in autumn is assumed to be 4 nominal of the whole station units. Therefore, to cover the remaining 110 kWh/day: $110 \text{ kWh} / 0.4 \text{ kW} = 69 \text{ panels}$
4. Nominal Power: $69 \text{ panels} \times 0.4 \text{ kW} = 27.6 \text{ kW}$
5. Total Area for Panels: $69 \text{ panels} \times 1.87 \text{ m}^2 = 129 \text{ m}^2$

Summer:

1. Wind Generation: In summer, the wind turbine's efficiency is 0.35. Therefore, the daily generation from a 5 kW wind turbine is: $5 \text{ kW} \times 0.35 \times 24 \text{ hours} = 42 \text{ kWh/day}$
2. Remaining Energy Demand: The total required energy is 170 kWh/day. Subtracting the wind turbine's generation: $170 \text{ kWh} - 42 \text{ kWh} = 128 \text{ kWh}$
3. Solar Panel Calculation: The daily solar panel generation in summer is assumed to be 6 nominal of the whole station. Therefore, to cover the remaining 128 kWh/day: $128 \text{ kWh} / 0.4 \text{ kW} = 53 \text{ panels}$
4. Nominal Power: $53 \text{ panels} \times 0.4 \text{ kW} = 21.2 \text{ kW}$
5. Total Area for Panels: $53 \text{ panels} \times 1.87 \text{ m}^2 = 99.1 \text{ m}^2$

The following table, Table 3.1.1.5, provides a detailed breakdown of the seasonal energy

generation and equipment requirements for a single household under the 1. Practical Energy Balancing Approach.

Season	Total Generation (kWh/day)	Wind Generation (kWh/day)	Remaining for Solar (kWh/day)	Panels Required	Total Panels Nominal Power (kW)	Total Area (m ²)
Winter	170	72	98	245	98	458
Autumn	170	60	110	69	27.6	129
Summer	170	42	128	53	21.2	99.1

Table 3.1.1.1: Equipment Requirements and Seasonal Energy Generation for a Household in the UHEVsA Model (1. Practical Energy Balancing Approach)

2. Physical Approach

The second approach assumes a calculation based on the maximum possible generation capacity of the household, considering physical limitations in terms of available space for installing equipment.

Roof area: For a typical medium-sized household, we assume the roof can support the installation of 8 kW of nominal solar panel capacity.

Land area: The household also has available land space for additional solar panels. For this calculation, we assume that 100 m² of land allows the installation of additional solar panels (60 panels on the land). Moreover, for enhanced generation efficiency, a 5 kW wind turbine can be installed.

The total energy generated with such equipment will depend on the season and type of generation, so for the calculations, we will use average generation values for different times of the year.

Comparison of the Two Approaches

Empirical Approach provides a clear estimate of the energy needs to cover household consumption and the charging of two electric vehicles.

Physical Approach helps assess the maximum possible generation capacity based on the installed equipment, allowing us to evaluate the optimal setup under ideal conditions.

Once the calculations for both approaches are completed, we will compare the results and determine the optimal configuration for each household.

Assumptions:

- 20 panels on the roof (totally 8 kW, 0.4 kW per panel)
- 60 panels on the land (totally 24 kW, 0.4 kW per panel)
- 5 kW wind turbine running 24 hours a day

- Solar panels generate different amounts of energy depending on the season:
 - Winter: 1 nominal per day
 - Spring/Autumn: 4 nominal per day
 - Summer: 6 nominal per day

Calculations:

1. Winter:

- Solar Generation:
 - $80 \text{ panels} \times 0.4 \text{ kW} = 32 \text{ kWh/day}$
- Wind Generation (with a coefficient of 0.6 for winter):
 - $5 \text{ kW} \times 24 \text{ hours} \times 0.6 = 72 \text{ kWh/day}$
- Total Generation = 32 kWh (solar panels) + 72 kWh (wind turbine) = 104 kWh/day

2. Spring/Autumn:

- Solar Generation:
 - $80 \text{ panels} \times 4 \times 0.4 \text{ kW} = 128 \text{ kWh/day}$
- Wind Generation (with a coefficient of 0.5 for spring and autumn):
 - $5 \text{ kW} \times 24 \text{ hours} \times 0.5 = 60 \text{ kWh/day}$
- Total Generation = 128 kWh (solar panels) + 60 kWh (wind turbine) = 188 kWh/day

3. Summer:

- Solar Generation:
 - $80 \text{ panels} \times 6 \times 0.4 \text{ kW} = 192 \text{ kWh/day}$
- Wind Generation (with a coefficient of 0.4 for summer):
 - $5 \text{ kW} \times 24 \text{ hours} \times 0.4 = 48 \text{ kWh/day}$
- Total Generation = 192 kWh (solar panels) + 48 kWh (wind turbine) = 240 kWh/day

The following table, Table 3.1.2.1, presents the seasonal energy generation and equipment requirements for a household under the 2. Physical Approach.

Season	Total Generation (kWh/day)	Wind Generation (kWh/day)	Solar Generation (kWh/day)	Panels Required	Total Panels Nominal Power (kW)	Total Area (m ²)
Winter	104	72	32	80	32	150
Spring/Autumn	188	60	128	80	32	150
Summer	236	42	192	80	32	150

Table 3.1.1.2: Seasonal Energy Generation and Equipment Requirements for a Household in the

UHEVsA Model (2. Physical Approach)

3. Combined Approach

Based on previous calculations, we are introducing a combined approach for the equipment selection. This approach involves considering the maximum generation capacity of a household, incorporating both wind and solar generation, along with energy storage systems.

Winter Generation Requirements: Initially, in winter, we calculated that the total daily generation from one 5 kW wind turbine (with a coefficient of 0.6) and 80 solar panels (generating 1 nominal per day) would give us 104 kWh/day. This value was calculated for one turbine.

However, since we require 170 kWh/day for winter generation, we need to adjust the system to meet the required generation.

Adjustment: To meet the required generation of 170 kWh/day during the winter season, we will add another wind turbine, bringing the total to two wind turbines.

This will ensure the total generation from both wind and solar sources meets the 170+ kWh/day target.

Calculation:

1. Wind Generation:

- Each 5 kW wind turbine generates:
 - Winter wind generation: $5 \text{ kW} \times 24 \text{ hours} \times 0.6 = 72 \text{ kWh/day}$ for one turbine.
 - With two wind turbines, the generation increases to: $72 \text{ kWh/day} \times 2 = 144 \text{ kWh/day}$.

2. Solar Generation:

- With 80 panels (0.4 kW per panel), the daily solar generation is:
 - $80 \text{ panels} \times 0.4 \text{ kW} \times 1 \text{ nominal} = 32 \text{ kWh/day}$ (for winter).

3. Total Generation in Winter:

- Wind generation (2 turbines): 144 kWh/day.
- Solar generation (80 panels): 32 kWh/day.
- Total generation = $144 \text{ kWh/day} + 32 \text{ kWh/day} = 176 \text{ kWh/day}$, which satisfies the 170 kWh/day requirement for winter.

Summary of Equipment for the Combined Approach:

- Wind Turbines: 2 turbines, each 5 kW.
- Solar Panels: 80 panels (0.4 kW per panel).
- Energy Storage: 100 kWh (Lithium Iron Phosphate batteries), allowing for overnight charging

of the vehicles.

The following table, Table 3.1.1.3, outlines the seasonal energy generation and equipment requirements for a household utilizing the Combined Approach.

Season	Total Generation (kWh/day)	Wind Generation (kWh/day)	Solar Generation (kWh/day)	Panels Required	Total Panels Nominal Power (kW)	Total Area (m²)
Winter	176	144	32	80	32	150
Spring/Autumn	248	120	128	80	32	150
Summer	288	96	192	80	32	150

Table 3.1.3: Seasonal Energy Generation and Equipment Requirements for the Combined Approach

The analysis concludes that the baseline energy requirement for the effective operation of UHEVsA is 170 kWh per day. This capacity is sufficient to supply a household's energy needs, fully charge a personal electric vehicle, and fully charge a guest's vehicle.

Meeting this demand requires a combination of renewable energy systems that include two 5 kW wind turbines and an 80-panel solar station, with each panel rated at 0.4 kW, giving a total nominal capacity of 32 kW. This configuration ensures sufficient generation across all seasons, even under varying environmental conditions. Additionally, the system requires energy storage units with a total capacity of 100 kWh, inverters for solar panels with a combined capacity of 30 kW, and wind inverters with a capacity of 10 kW to manage and balance energy generation, storage, and distribution effectively.

To ensure a daily generation of 170 kWh, a combined solar and wind power station with a total capacity of 42 kW is required. The combined station consists of 73% solar and 23% wind power.

Moreover, the physical feasibility of such a setup is well within the constraints of an average household. A land area of 100m² can be allocated for a ground-mounted solar station, while rooftop installation can accommodate additional panels. Together, this setup maximizes energy production without exceeding spatial limitations, demonstrating the practicality and scalability of the UHEVsA model in suburban households.

If both electric vehicles in the UHEVsA system are utilized to supply energy to donor households, each vehicle will reserve 15 kWh for mobility purposes. Considering energy losses during vehicle discharge, inverter operation, and the charge-discharge cycle of the donor household system, which are estimated at 30%, the total energy available for transfer per day will be:

$$(55 - 13) \times 2 \times 0.7 = 58.8 \text{ kWh}$$

Thus, approximately 60 kWh could be delivered from one household to the end consumers, representing around 35% of the initially generated 170 kWh by one household. This demonstrates the potential of integrating EVs as energy sources within the UHEVsA model, while accounting for system inefficiencies and mobility requirements.

Thus, one household generating electricity (a donor) can supply energy to six households (acceptors) with 10 kWh per day each. This setup requires the involvement of at least two electric vehicles.

Each acceptor household must be equipped with a 10 kWh storage unit and a 5 kW inverter to manage the received energy.

Additionally, for each apartment building entrance, shared equipment should be installed in a technical room or basement. This includes storage units with a capacity of 12.5 kWh per household and inverters with a capacity of 5 kW per household. For example, for a single entrance in a ten-story building with 40 apartments (4 apartments per floor), the required shared equipment would consist of 500 kWh of storage capacity and 200 kW of total inverter capacity.

The number of dischargers per apartment building entrance is calculated based on:

$$12.5 \text{ kWh} / 24 \text{ hours} = 0.52 \text{ kW per household.}$$

For 40 apartments (one entrance), this equals:

$$0.52 \text{ kW} \times 40 = 21 \text{ kW.}$$

This capacity will be distributed across 6 dischargers, each with a capacity of 3.5 kW.

Consequently, an electric vehicle will discharge 40 kWh over a period of approximately 11.4 hours.

Below, Table 3.1.1.4 summarizes the key equipment required for a single donor household and a single acceptor household in the UHEVsA model.

Item	Donor Household	Acceptor Household
Renewable Energy Systems	Two 5 kW wind turbines and an 80-panel solar station (32 kW total)	Not applicable
Energy Storage Units	100 kWh	22.5 kWh
Inverters	30 kW for solar, 10 kW for wind	10 kW
Charging/discharging Stations	Two 7 kW stations	0.52 kW

Table 3.1.1.4: Equipment Requirements for Donor and Acceptor Households in the UHEVsA

Model

3.1.2. Energy Demand and Supply Balance Between Donors and Acceptors

The energy demand required to meet the basic household needs of urban populations (donors) and the ability of suburban households (acceptors) to supply this demand through decentralized energy generation systems, such as solar panels and wind turbines, should be assessed.

The daily energy consumption required for urban residents, which includes typical household needs such as lighting, wi-fi, internet and running appliances, should be estimated. Based on average energy consumption per person in Ukrainian cities, the total daily energy demand for city dwellers should be calculated.

Heating and cooking costs are not included in the calculation as we assume that in extreme conditions, people will switch to alternative heating sources (such as compact gas or kerosene heaters) and compact gas stoves for cooking.

According to the State Statistics Service of Ukraine, in 2021, the total electricity consumption by the population amounted to 38.7 billion kWh and the resident population of Ukraine was estimated to be 41.2 million people on December 1, 2021.(State Statistics Service of Ukraine, 2021).

With a current population estimate of 34 million (Черновол, 2023) and no direct consumption data, we can approximate the consumption as

$$(38.7/41.2)*34 = 31.9 \text{ billion kWh,}$$

based on a previous consumption of 38.7 billion kWh for a population of 41.2 million.

Calculating daily per capita consumption yields:

$$31,900,000,000 \text{ kWh} / 34,000,000 \text{ people} / 365 \text{ days} \approx 2.6 \text{ kWh.}$$

Given our earlier estimate of 10 kWh daily household consumption and assuming a household size of 3-4, this translates to 7.8-10.4 kWh per household daily, which is consistent with our previous assumption.

To meet an annual household consumption of 31.9 billion kWh, 1,468,861 private households would need to install 42 kW power stations that can generate 170 kWh per day:

$$31,900,000,000 \text{ kWh} / 365 \text{ days} / (170 * 0.35) \text{ kWh per day} = 1,468,861 \text{ private households.}$$

These calculations assume a generation capacity during the winter period when solar generation is at its lowest.

As shown in Table 3.1.2.1. Characteristics of Households' Housing in Ukraine (2022), based on data from the State Statistics Service of Ukraine (State Statistics Service of Ukraine, 2022), the

number of individual residential houses in Ukraine as of 2022 accounted for 49.1% of the total 14,549,200 households, which is approximately 7,141,637 individual houses. This number exceeds the 1,468,861 private households required to provide the necessary generation capacity by approximately 4.9 times.

Характеристика житла домогосподарств

Characteristics of households' housing

	Всі домогосподарства/all households		у тому числі, які проживають (%)/including living (%)							
			у міській місцевості/in urban areas			у сільській місцевості/in rural areas				
	2021	2022	у великих містах/in big cities	у малих містах/in small towns	всього/total		2021	2022	2021	2022
			2021	2022	2021	2022				
Кількість домогосподарств (тисяч)	14678,1	14549,2	5767,1	4096,6	9944,0	9863,7	4734,1	4685,5	Number of households (thousands)	
Розподіл домогосподарств (%) за типом житла:	Distribution of households (%) by type of housing:									
окрема квартира	46,3	47,3	81,8	48,1	66,1	67,8	4,7	4,1	separate apartment	
комунальна квартира	0,4	0,2	0,6	0,1	0,6	0,4	0,1	-	communal apartment	
індивідуальний будинок	49,3	49,1	12,6	48,4	28,1	27,5	93,9	94,5	individual house	
частина індивідуального будинку	1,9	1,7	1,4	2,4	2,2	1,8	1,3	1,4	part of an individual house	
гуртожиток	2,1	1,7	3,6	1,0	3,0	2,5	-	-	hostel	
	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0		

Table 3.1.2.1. *Characteristics of Households' Housing in Ukraine (2022)*. Data from the State Statistics Service of Ukraine. (State Statistics Service of Ukraine, 2022)

The potential estimated generation capacity of all individual households in Ukraine is significant. Assuming each household generates 170 kWh per day, the total annual generation for these households would theoretically be:

$$7,141,637 \times 170 \text{ kWh/day} \times 365 \text{ days} = 443.8 \text{ billion kWh}$$

However, accounting for system losses and the fact that only 35% of the generated energy reaches the final consumer, the effective annual contribution would be:

$$443.8 \text{ billion kWh/year} \times 0.35 = 155.3 \text{ billion kWh/year.}$$

This adjusted capacity is still approximately 4.9 times greater than the 31.9 billion kWh electricity consumption previously estimated as necessary to meet annual requirements. Furthermore, it represents 1.003 times the total electricity consumption of the country in 2021, which, according to national statistics, was 154.8 billion kWh.

These calculations highlight the significant potential of distributed household energy generation in Ukraine, even when accounting for system inefficiencies. This potential demonstrates the feasibility and importance of leveraging individual households as key contributors to the country's energy system, ensuring both sustainability and resilience.

From the previous calculations, it is evident that a single donor household can theoretically supply

energy to approximately six recipient households. At the same time, as shown in Table 3.1.2.1, the number of individual donor households is proportional to the number of recipient households on a 1:1 basis. This means that it would be sufficient for one donor household to supply one recipient household. With this approach, the nominal generation capacity could be reduced by a factor of 4.9, i.e., to $42 \text{ kW}/4.9 = 8.6 \text{ kW}$. However, considering the lack of practical applications and the simplified model description, which does not account for many details and potential bottlenecks affecting the feasibility and adequacy of the UHEVsA system, it is more prudent to adopt a decision with a margin. Therefore, it is recommended to set the generation capacity for all possible households at 42 kW or more.

Additionally, as shown in Table 3.1.2.1, the ratio of individual donor households to the remaining recipient households in large cities is 1 to 6.14 (14 to 86), in small cities it is 1 to 1 (50.6 to 49.4), and in rural areas it is 24 to 1 (95.9 to 4.1). Thus, only in large cities is the donor-to-recipient ratio 25% greater than the previously calculated sufficient ratio of 1 to 4.9. However, considering that this discrepancy is not significant, and given that small satellite cities are usually located around large cities, where the ratio is 1 to 1, this difference can be disregarded.

This section provides a preliminary estimate of the energy balance between donors and acceptors. By assessing the energy needs of urban populations and the generation potential of suburban households, the feasibility of UHEVsA in meeting energy demands and ensuring energy security was better understood.

3.1.3. EV Capacity and Role in the UHEVsA Model

The integration of electric vehicles (EVs) into the UHEVsA model plays a critical role in ensuring the efficient and reliable functioning of decentralized energy systems, particularly during periods of crisis or when central grid infrastructure is unavailable. In this section, we will explore the potential of EVs as both energy storage units and distributors, assessing their capacity to support energy needs for households and businesses, and their ability to enhance the resilience of the overall energy system.

To begin, it is essential to determine the number of electric vehicles required per household or business to ensure that they can effectively contribute to energy distribution during emergencies. Each household or business in the UHEVsA model will need to have at least one EV that can store enough energy to meet its daily needs and provide additional energy to support other users in the community. The capacity of the vehicle's battery is a crucial factor in this process. The typical EV battery capacity can range from 50 kWh to 100 kWh, depending on the vehicle model. This capacity determines how

much energy can be stored and later used or redistributed, either for household consumption or as part of the broader community energy network.

Another key aspect is evaluating the daily use of EVs. These vehicles are not only used for transportation but also serve as storage units that can store excess energy generated from renewable sources, such as solar panels and wind turbines. In situations where energy generation from renewable sources is insufficient, the stored energy in EV batteries can be transferred back to the grid or used directly by other local systems. The ability of EVs to store energy and transfer it back to the grid is known as Vehicle-to-Grid (V2G) technology. V2G technology plays a pivotal role in balancing energy supply and demand, particularly in decentralized energy systems where the availability of energy can fluctuate due to the intermittent nature of renewable sources.

The number of EVs required per household or business will depend on the specific energy needs of that unit and the vehicle's battery capacity. For instance, if a typical household requires 10 kWh of energy per day, and an EV with a 55 kWh battery is available, this vehicle can store sufficient energy for several days of consumption or provide energy to other units during low generation periods. The size and number of EVs required may increase depending on the energy demands of larger businesses or communities.

Furthermore, EVs can supply energy to other local systems, such as homes, businesses, and local grids, particularly when renewable energy generation is insufficient. This becomes increasingly important in scenarios where solar and wind energy generation is at its lowest, such as on cloudy days in the winter or during periods of low wind. During these times, the capacity of EVs to provide energy can make the difference between a reliable energy supply and a potential shortfall. In addition to energy storage and distribution, EVs can also serve as mobile power sources, enabling energy to be transferred across communities, thus enhancing the overall resilience of the system.

As previously noted, we assume that the battery capacity of a single electric vehicle (EV) is 55 kWh, of which 13 kWh is reserved for the daily operation of the vehicle for distances ranging from 50 to 100 km. Additionally, we account for a 30% energy loss during the transmission process. Based on this, we will estimate the required number of electric vehicles with a capacity of 55 kWh or more using two methods.

The first method involves calculating the total energy consumption, dividing it by 365 days, and then dividing by the available energy capacity of one vehicle (42 kWh, after reserving 13 kWh for daily transportation), while factoring in the 30% loss. The calculation is as follows:

$$31,900,000,000 \text{ kWh} \div 365 \text{ days} \div 42 \text{ kWh} \div 0.7 \approx 2,972,695 \text{ EVs.}$$

The second method is based on the number of households serving as energy donors. Given that each household charges two vehicles per day, we multiply the number of households by two:

$$1,468,861 \text{ households} \times 2 \text{ EVs per household} = 2,937,722 \text{ EVs.}$$

By comparing the results from both methods, we conclude that the minimum required number of electric vehicles is approximately 3 million. However, in reality, more vehicles may be needed, as not every vehicle will be utilized for transportation and energy transmission on a daily basis. A more accurate estimation would require a separate, more complex model, which lies beyond the scope of this research.

As of now, the number of electric vehicles in Ukraine is 120,000, which is 25 times less than the required number of 3 million vehicles (source: DW).

Let's examine the dynamics of electric vehicle registrations to assess the trends and the time required to achieve the needed number. In 2021, 15,900 vehicles were sold, in 2022 – 23,000, and in 2023 – 54,200. Thus, to reach the required number of 3 million vehicles with the existing growth rate, it will take approximately 4.7 years.

The implementation of the UHEVsA model is primarily aimed at ensuring energy stability in the context of Russia's military aggression, which will help remove the lever of terror used by the aggressor against the population of Ukraine. Therefore, achieving the necessary number of electric vehicles should occur within 1–2 years. Given that the estimated time to reach the required number of 3 million vehicles is 4.7 years, the process must be intensified, which also dictates the need to assess the possibility of such an acceleration.

Currently, there are 12 million passenger cars of all types in Ukraine. Adding 3 million electric vehicles to this number would result in electric cars accounting for 20% of the total vehicle fleet (DW, 2023).

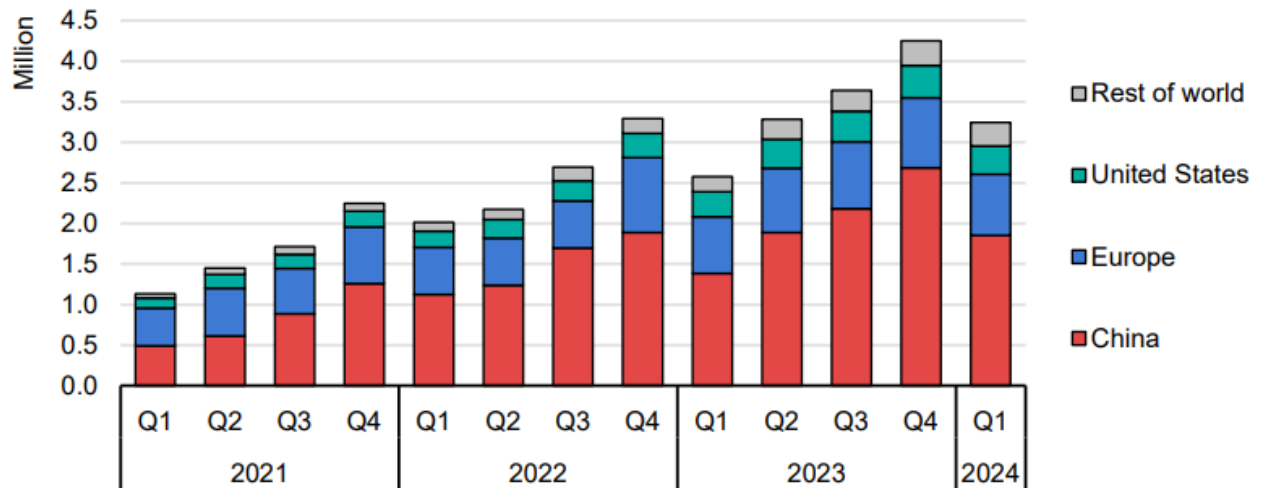
The number of cars of all types registered in 2023 was 411,000 (HSC.gov.ua, 2024). Therefore, if it is necessary to register 1.5 million vehicles (i.e., the pace required to reach the 3 million mark in 2 years) within 1 year, the workload will increase by a factor of $1.5 \text{ million} / 411,000 \approx 3.65$ times.

This increase will raise the load on the registration system by 3.65 times, but with the availability of remote registration via the Diia portal, this should not cause critical overload.

The number of electric vehicles sold from 2021 to the first quarter of 2024 is shown in the

diagram below.

Quarterly electric car sales, 2021-2024



IEA. CC BY 4.0.

Source: IEA analysis based on data from on EV Volumes, China Passenger Car Association and the European Automobile Manufacturers' Association.

Figure 3.1.3.1. Quarterly Electric Car Sales, 2021-2024. (2024, International Energy Agency).

As seen in the diagram, in one quarter of 2023, approximately 2 million vehicles were sold in China, 1 million in Europe, 0.4 million in the USA, and 0.3 million in the rest of the world. The total number of electric vehicles sold in 2023 was 14 million.

Thus, to quantitatively supply Ukraine with 1.5 million electric vehicles per year, 10% of the global volume is required, which is a realistically achievable target. However, the construction of logistics chains, which is beyond the scope of this study, requires further investigation.

EVs have a significant role to play in the UHEVsA model by acting as mobile energy storage units, supporting local energy production, and facilitating energy distribution in times of crisis or when renewable energy generation is insufficient. By understanding the capacity of EVs to store and supply energy, the UHEVsA system can be optimized to ensure energy security and sustainability, even in regions where the central grid is unreliable or unavailable.

3.1.4. Scalability Considerations

In the context of the UHEVsA model, scalability refers to the ability of the proposed energy generation system to expand and adapt to increasing energy demands or additional households and businesses within the decentralized network. Scalability is a crucial factor to consider when designing

the UHEVsA system, as it needs to accommodate future growth while maintaining efficiency and reliability.

Key scalability considerations for the UHEVsA model include:

Energy Generation Capacity:

- **Expansion of Solar Panels:** As energy demand increases, the number of solar panels can be increased proportionally, assuming the available space on rooftops and land allows for it. Each additional 0.4 kW solar panel adds to the total generation capacity, with adjustments for seasonal performance and geographic location. The system must account for available space for expansion when determining the maximum number of solar panels that can be installed.
- **Wind Turbine Integration:** Wind generation scalability is also essential. While the current model considers two 5 kW wind turbines, the future scalability may involve adding more turbines to meet growing energy needs. The decision to scale wind generation should consider local wind conditions, environmental factors, and available land. The model can be adjusted to increase the number of turbines incrementally to match increased demand.
- **Urban Energy Supply:** If the energy generated by suburban households fell short of the demand from urban residents, additional measures to enhance energy supply were explored. One such measure was the installation of solar panels on the rooftops of multi-story apartment buildings in urban areas, which would reduce the burden on suburban households and increase the overall energy generation capacity within the cities.

Energy Storage Expansion:

- **Battery Capacity:** As more energy is generated, especially with the scaling of solar panels and wind turbines, the demand for storage capacity will increase. The existing 100 kWh storage system for the household could be scaled up to accommodate additional energy generated during peak periods or from expanded systems. Lithium Iron Phosphate (LiFePO₄) batteries could be added or their capacity increased to meet the growing energy generation needs.
- **Efficiency of Storage Systems:** Scaling up energy storage will also require optimizing the efficiency of storage systems. The scalability of the storage infrastructure must be assessed to ensure that the storage-to-generation ratio remains adequate and effective in handling energy during low-generation periods (e.g., winter) without overloading the system.

Increasing Electric Vehicles and Battery Capacity:

- Another crucial aspect of scalability is the growing number of electric vehicles (EVs) and their battery capacity. As more households adopt EVs, the energy demand will increase. At the same time, the battery capacity of these vehicles is expanding, offering more potential for energy storage and distribution within the system. Furthermore, installing portable solar panels on the roofs or bodies of EVs could further boost energy generation by harnessing solar power during daylight hours, enhancing both the sustainability and scalability of the model.
- Additionally, communities can leverage more powerful vehicles with larger batteries, such as electric trucks and buses, to further amplify energy storage and distribution capabilities. These larger vehicles could act as mobile energy hubs, capable of supporting energy exchange between households and providing backup power to critical infrastructure during emergencies. With their substantial battery capacity, they could play a pivotal role in ensuring energy stability and scalability in regions with high demand.

Charging and Discharging Speeds:

- The rate at which EV batteries charge and discharge is an important factor for scalability. As the number of EVs increases, improving the speed of charging and discharging is essential for maintaining system efficiency. This improvement would ensure that energy is rapidly stored during peak generation times and discharged when needed, helping to balance supply and demand across the network.

Integration of Multiple Households or Businesses:

- **Energy Sharing and Management:** As the number of participants in the system increases, energy sharing, management, and transactions must be optimized. The UHEVsA model must consider how multiple households or businesses can seamlessly share and distribute energy, ensuring a balance of generation and consumption across the decentralized network.

Technological Advancements:

- **Emerging Technologies:** As new technologies for solar, wind, and energy storage emerge, scalability must factor in the integration of these innovations. More efficient solar panels, better battery technologies, and improved wind turbine designs could significantly enhance the overall capacity and efficiency of the UHEVsA system, supporting its growth over time.

Optional Scalability with Microhubs:

- An additional scalability consideration involves the optional installation of microhubs, typically with capacities ranging from 3 to 5 MW, near distribution substations 10/0.4kV. These microhubs could serve as local energy centers, enabling more localized energy generation and distribution. With microhubs installed in strategic locations, it would be possible to optimize the energy network by providing additional power close to areas with higher demand. This approach aligns with the decentralization model, promoting greater flexibility and resilience in the overall energy system while reducing transmission losses.

3.1.5. Investment Comparisons

In this subsection, we will examine the financial implications of implementing the UHEVsA system compared to the costs of maintaining or upgrading the existing centralized grid infrastructure. This analysis will highlight the investment required for both systems and allow for a clear comparison, particularly in the context of Ukraine's current energy crisis, which has highlighted the need for resilient, decentralized energy solutions.

The implementation of the UHEVsA system involves several key costs, including the purchase and installation of equipment such as solar panels, wind turbines, batteries, and electric vehicles (EVs). Additionally, there are ongoing maintenance costs associated with ensuring the system's operational efficiency and longevity. The cost of solar panels, for example, depends on the number of panels required to meet energy generation needs, with each panel typically providing 0.4 kW of nominal power. Wind turbines, which are another crucial component of the system, come with their own set of costs, which include the purchase, installation, and maintenance of turbines. Energy storage, particularly lithium iron phosphate (LiFePO₄) batteries, is also a significant cost in the UHEVsA model, as these batteries are necessary for storing excess energy generated during peak periods for use during low-generation times. The cost of EVs, which serve as mobile energy storage units, is also an important consideration, especially when calculating the total investment required for households and businesses to fully implement the UHEVsA system.

To understand the full financial commitment, we must also account for installation costs, which can vary depending on the complexity of the system and the specific needs of each household or business. Installation costs may include the setup of solar panels on rooftops, the positioning of wind turbines on available land, and the necessary electrical work for integrating the energy storage and EV systems. Additionally, ongoing maintenance is required to ensure the system operates efficiently over

time. These maintenance costs are typically lower than those associated with centralized grid infrastructure, as renewable energy systems require less frequent repairs and have fewer moving parts.

Financial implications of implementing UHEVsA system

Below is an estimated cost breakdown for the required equipment and installation to set up a UHEVsA system for both a donor household and an acceptor household. The costs are provided in both Ukrainian Hryvnias (UAH) and U.S. Dollars (USD) for clarity, and they cover key components such as wind turbines, solar panels, energy storage, inverters, and charging/discharging stations. The installation costs for setting up the entire system are also included. These figures are approximate and can vary depending on specific suppliers and local conditions.

Item	Estimated Cost in UAH	Estimated Cost in USD
Wind Turbines (2 x 5 kW)	240,000 - 300,000 UAH	\$6,667 - \$8,333
Solar Panels (80 panels, 32 kW)	320,000 - 384,000 UAH	\$8,889 - \$10,667
Energy Storage (100 kWh)	150,000 - 200,000 UAH	\$4,167 - \$5,556
Solar Inverter (30 kW)	70,000 - 100,000 UAH	\$1,944 - \$2,778
Wind Inverter (10 kW)	40,000 - 50,000 UAH	\$1,111 - \$1,389
Charging/Discharging Stations (2 x 7 kW)	60,000 - 80,000 UAH	\$1,667 - \$2,222
Installation Costs (Solar, Wind, Batteries, Charging Stations)	100,000 - 160,000 UAH	\$2,778 - \$4,444
Equipment		\$23,444 - \$31,389
Installation		\$2,778 - \$4,444
Total		\$26,222 - \$35,833

Table 3.1.3.1. Estimated Costs for UHEVsA System Equipment and Installation for Donor Households

Item	Estimated Cost in UAH	Estimated Cost in USD
Energy Storage (22.5 kWh)	40,000 - 60,000 UAH	\$1,111 - \$1,667
Inverter (10 kW)	30,000 - 50,000 UAH	\$833 - \$1,389
Charging/Discharging Station (0.52 kW)	5,000 - 8,000 UAH	\$139 - \$222
Installation Costs (Energy Storage, Inverter, Charging Station)	30,000 - 50,000 UAH	\$833 - \$1,389

Equipment		\$1,944 - \$3,278
Installation		\$833 - \$1,389
Total		\$2,778 - \$4,667

Table 3.1.3.2. Estimated Costs for UHEVsA System Equipment and Installation for acceptor Households

Earlier, we calculated that the number of donor households required for the UHEVsA system is 1,456,621, and the number of acceptor households is 7,405,542. Therefore, the investment required for donors is calculated as follows:

$$1,456,621 * \$31,027 = \$45,157,954,557.$$

The investment required for acceptors is calculated as:

$$7,405,542 * \$3,722 = \$27,593,697,447.$$

Additionally, we calculated that for the successful implementation of UHEVsA, we need 3 million electric vehicles. The total cost of these vehicles, given the average price of an electric vehicle with a battery capacity of 60-100 kWh in Ukraine, is as follows:

$$3,000,000 * \$32,500 = \$97,500,000,000.$$

Thus, the total initial investment cost for UHEVsA implementation will amount to:

$$\$45,157,954,557 + \$27,593,697,447 + \$97,500,000,000 = \$170,251,651,005.$$

To facilitate the successful implementation of UHEVsA, the government could focus its support on three key areas: donor generation systems, acceptor households, and electric vehicle acquisition. For donor households, the government can provide support through zero-interest loans, grants, and exemption from import duties on renewable energy equipment. For acceptor households and electric vehicle purchases, the government’s assistance could include favorable loan conditions through banks and import duty exemptions, particularly on electric vehicles.

Providing zero-interest loans for the installation of generation systems in donor households over a 7-10 year period would cost the government approximately 50% of their total value. Thus, the government’s expenditure to support the establishment of generation systems would amount to:

$$\$45,157,954,557 * 0.5 = \$22,578,977,278.50.$$

Additionally, import duty exemptions on electric vehicles and equipment for donors and acceptors would result in costs to the government equal to 30% of their total value. This is calculated as:

$$(\$45,157,954,557 + \$27,593,697,447 + \$97,500,000,000) * 0.3 = \$51,376,980,900.20.$$

In total, the government’s expenditure to support the UHEVsA system implementation through

these measures would amount to:

$$\$22,578,977,278.50 + \$51,376,980,900.20 = \$73,955,958,178.70.$$

Costs of maintaining or upgrading the existing centralized grid infrastructure

To ensure the electricity consumption of the population is met over a year with a total demand of 31.9 billion kWh, it is crucial to calculate the nominal capacity required. Assume that an average capacity factor is 50%.

However, taking into account approximately 10% transmission and distribution losses, the efficiency coefficient decreases further, resulting in an overall efficiency of 40%. This highlights the need to generate more energy to compensate for these additional losses and ensure reliable delivery to end consumers.

The necessary nominal capacity can be calculated using the following formula:

$$\text{Nominal Capacity (GW)} = \frac{\text{Annual Energy Demand (kWh)}}{(\text{Hours per Year} \times \text{Efficiency})}$$

$$\text{Nominal Capacity} = \frac{31,900,000,000}{(365 \times 24 \times 0.4)} = 9.1 \text{ GW}$$

Thus, the nominal capacity required to supply the annual energy demand of 31.9 billion kWh is 9.1 GW.

Cost Analysis for Constructing 9.1 GW Capacity

The cost of constructing 9.1 GW of generation capacity depends on the type of energy source utilized. Below is an analysis of estimated costs for different types of generation technologies based on average global benchmarks:

1. Wind Power Plants

Average cost: \$1,200 - \$1,800 per kW

2. Solar Power Plants

Average cost: \$800 - \$1,200 per kW

3. Thermal Power Plants

Average cost: \$1,000 - \$2,500 per kW

4. Nuclear Power Plants

Average cost: \$5,000 - \$9,000 per kW

Total cost:

Average Cost per kW for each type of power plant:

$$\text{Wind: } \frac{1,200 + 1,800}{2} = 1,500 \text{ \text{\$} / }$$

$\text{kW} 21,200 + 1,800 = 1,500 \text{ \$/kW}$

Solar: $800 + 1,200 = 1,000 \text{ \$/kW}$ $\frac{800 + 1,200}{2} = 1,000$, $\text{\$/kW}$ $2800 + 1,200 = 1,000 \text{ \$/kW}$

Thermal: $1,000 + 2,500 = 1,750 \text{ \$/kW}$ $\frac{1,000 + 2,500}{2} = 1,750$, $\text{\$/kW}$ $21,000 + 2,500 = 1,750 \text{ \$/kW}$

Nuclear: $5,000 + 9,000 = 7,000 \text{ \$/kW}$ $\frac{5,000 + 9,000}{2} = 7,000$, $\text{\$/kW}$ $25,000 + 9,000 = 7,000 \text{ \$/kW}$

Overall average cost per kW:

$$\text{Overall Average Cost per kW} = 1,500 + 1,000 + 1,750 + 7,000 = 2,812.50 \text{ \$/kW}$$

Total Cost for 9.1 GW Based on Average Cost:

$$\text{Total Cost} = 9,100,000.00 \text{ kW} \times 2,812.50 \text{ \$/kW} = 25,593,750,000.00 \text{ \$}$$

The total government expenditure for constructing the centralized grid with a nominal capacity of 9.1 GW is approximately \$25.6 billion, while the total expenditure for supporting the UHEVsA system through zero-interest loans and import duty exemptions amounts to \$73.96 billion.

Thus, the cost of supporting the UHEVsA system is approximately 2.9 times higher than the cost of constructing the centralized grid.

However, it should be noted that \$51 billion of the \$73 billion are not direct expenditures requiring funding but rather forgone revenues, especially since these zero import duties are already in effect. Additionally, it is important to emphasize that the \$22 billion required to cover the cost of servicing zero-interest loans would be distributed over a period of 7-10 years.

Additionally, when comparing the actual expenditures, the ratio becomes nearly 1.16:1, as the direct costs to the government for constructing the centralized grid are \$25.6 billion, while the cost for servicing zero-interest loans for the UHEVsA system is \$22 billion. This indicates that, in terms of real funding required, both options are very similar in financial impact for the government.

Comparing these costs with the expenses of repairing and upgrading centralized grid infrastructure is essential to understanding the financial viability of the UHEVsA system. Centralized grid systems require continuous investment in maintenance and upgrading, particularly in the context of Ukraine's current energy crisis, which has resulted in widespread damage to the national grid. The costs of repairing and upgrading the grid infrastructure are substantial, involving the restoration of power lines, transformers, and other critical components that have been damaged or are outdated. Moreover, maintaining centralized systems, especially in a wartime scenario, poses additional challenges, such as the risk of further damage to infrastructure and the need for constant vigilance to

prevent system failures.

When comparing these two options, it becomes clear that the UHEVsA system offers a more flexible and resilient solution, especially for households and businesses in areas where centralized grids are unreliable or unavailable. In addition to the direct costs of implementation, the UHEVsA model offers long-term savings in energy bills for households and businesses. By generating their own energy, consumers can reduce their reliance on expensive and unstable centralized electricity, leading to significant reductions in monthly energy costs. Furthermore, the potential for energy sharing between households and businesses can help offset the costs of initial investment, as energy surpluses can be sold or shared with others.

Government and incentive support also plays a critical role in the overall cost of implementing UHEVsA. Subsidies, tax credits, and grants can significantly reduce the initial investment required for households and businesses to adopt the system. For example, government programs designed to promote renewable energy can help offset the cost of purchasing solar panels, wind turbines, and batteries. These financial incentives can make the UHEVsA system more accessible, particularly in regions where energy independence is crucial. Additionally, savings in energy bills can further reduce the payback period for UHEVsA systems, making them an economically viable alternative to centralized grid infrastructure.

While the initial investment in the UHEVsA system may be significant, the long-term savings, flexibility, and resilience it offers make it an attractive alternative to repairing and upgrading centralized grid infrastructure. The financial comparison between these two options highlights the potential of decentralized energy systems to provide sustainable, cost-effective solutions, particularly in areas where centralized grids are compromised or unreliable.

3.1.6. Feasibility of UHEVsA as a Primary Power Supply

This subsection evaluates the overall feasibility of utilizing the UHEVsA (Home-EVs-Apartment) model as a primary energy system. The assessment covers technical, economic, and regulatory factors, and compares the effectiveness of the UHEVsA system with traditional centralized grids, especially in crisis scenarios where the conventional infrastructure may be compromised or non-existent.

Technical Feasibility

The technical feasibility of UHEVsA as a primary energy system depends on the successful integration of decentralized energy sources, including solar power, wind energy, and electric vehicles (EVs). Each component of the system must work autonomously to ensure continuous energy supply,

particularly when the centralized infrastructure is unavailable or unreliable. Solar panels and wind turbines, installed at households and businesses, will generate energy independently. The role of EVs as mobile energy storage units further enhances this system, allowing energy to be stored and distributed when needed.

To assess the technical feasibility, we must consider the capacity of these decentralized systems to generate and store sufficient energy to meet daily demands. The integration of solar and wind power is particularly crucial during different seasons, as the generation capacity will fluctuate based on sunlight and wind availability. EVs play a vital role in stabilizing this system by storing excess energy and providing a buffer during low-generation periods, such as during cloudy days or windless nights.

Given these factors, the UHEVsA system can be designed to operate independently during extended outages or infrastructure failures. The ability to balance generation and consumption through energy storage, coupled with the flexibility provided by EVs, makes UHEVsA technically feasible as a reliable primary energy source.

Economic Feasibility

The economic feasibility of the UHEVsA system hinges on several factors: the initial capital investment, the cost of operation and maintenance, and the long-term savings generated by reduced dependence on centralized energy sources. While the upfront costs for installing solar panels, wind turbines, and energy storage systems can be significant, the long-term operational savings are considerable. Households and businesses adopting the UHEVsA system can reduce their reliance on expensive and unstable electricity from centralized grids, thus lowering their energy bills.

The scalability of the system is also a key consideration. As the number of participating households and businesses increases, the overall cost per unit of energy generated decreases, making UHEVsA an increasingly viable option. Furthermore, the system's economic viability is enhanced by the potential for energy sharing between households, allowing for more efficient distribution of energy surpluses.

When compared to maintaining or upgrading centralized grids, UHEVsA presents a more sustainable and cost-effective alternative, particularly in regions facing energy instability due to geopolitical or environmental challenges. The cost of repairing and maintaining centralized infrastructure, especially in the wake of significant damage (such as during wartime), can far exceed the costs of implementing a decentralized energy system like UHEVsA.

Regulatory Feasibility

The regulatory feasibility of implementing UHEVsA is closely tied to existing laws and policies

surrounding renewable energy, decentralized energy systems, and electric vehicles in Ukraine. Currently, Ukraine has some regulatory frameworks in place for renewable energy systems, but these may need to be expanded or adapted to fully support the widespread adoption of UHEVsA.

For instance, the current legal framework does not fully address the integration of decentralized energy systems and EVs at the scale required for the UHEVsA model. Policies promoting renewable energy adoption, energy storage, and electric vehicles must be revisited and strengthened to accommodate this new approach. Incentives such as subsidies, tax breaks, and grants for installing solar panels, wind turbines, and EVs can play a significant role in making UHEVsA more accessible and economically attractive for households and businesses.

Moreover, regulatory challenges related to grid integration, energy sharing, and energy transactions (potentially facilitated by blockchain technology) will need to be addressed. Clear legal frameworks must be established to ensure the smooth operation of UHEVsA systems, particularly as they scale up and become more interconnected.

Comparison with Grid System

In comparing the UHEVsA system to traditional centralized grids, several key factors must be considered: reliability, resilience, and the ability to provide consistent energy supply during power outages or infrastructure failures. Centralized grids are vulnerable to disruptions caused by external factors such as natural disasters, geopolitical conflicts, or aging infrastructure. When these grids fail, it can lead to widespread power outages, with long recovery times.

UHEVsA, on the other hand, offers a more resilient and flexible energy solution. By decentralizing energy generation and storage, UHEVsA can continue to operate even when centralized systems fail. Energy is generated locally through solar panels and wind turbines, stored in batteries, and distributed through electric vehicles, ensuring that households and businesses have access to energy even during periods of high demand or low generation.

Furthermore, UHEVsA's ability to provide energy sharing and dynamic energy exchanges between households, businesses, and EVs allows for a more adaptive energy system. Unlike traditional grids, which are limited by their physical infrastructure, UHEVsA can respond more quickly to changes in energy demand and supply, making it a more resilient and sustainable energy model.

UHEVsA presents a technically viable, economically feasible, and potentially regulatory-friendly alternative to centralized energy systems. While some regulatory and infrastructure challenges remain, the UHEVsA model offers significant potential to enhance energy resilience, particularly in regions facing energy insecurity or infrastructure instability. By leveraging decentralized renewable energy

generation and storage, UHEVsA can provide a sustainable and reliable energy supply, even in crisis situations.

3.2. Development of a Mobile Application for Monitoring and Energy Transactions

The development of a mobile application is a crucial component of the UHEVsA (Home-EVs-Apartment) model, ensuring efficient energy management and enhancing user experience. The proposed mobile application will enable users to monitor, manage, and engage in energy transactions in real-time, providing a seamless interface for tracking energy production, consumption, and storage. This section outlines the key features of the mobile app, its functionality, and its integration with the broader UHEVsA system.

3.2.1. App Functionality

Real-Time Monitoring

A fundamental feature of the mobile app will be real-time monitoring of energy generation, consumption, and storage. Users will be able to track the performance of various energy sources such as solar panels, wind turbines, and other renewable energy systems installed within their homes or businesses. The app will also provide data on the energy stored in batteries and electric vehicles (EVs). This functionality will allow users to visualize their energy usage patterns and optimize their systems accordingly, ensuring they meet both their energy needs and sustainability goals.

The real-time monitoring system will display key metrics such as energy produced by solar panels, wind turbines, and other systems, as well as the remaining energy stored in batteries and EVs. Users can set preferences to receive notifications or alerts based on energy performance, ensuring proactive management of their energy systems.

Energy Exchange Management

A critical aspect of the UHEVsA model is the exchange of energy between households, businesses, and EVs. The mobile app will facilitate the management of these energy exchanges, ensuring that the flow of energy between participants is efficient, secure, and cost-effective.

The app will support peer-to-peer energy trading, allowing users to send or receive energy based on their consumption needs or excess energy generation. For instance, a household with excess solar generation can transfer surplus energy to another household, business, or an EV owner, effectively creating a local energy market. The app will calculate energy credits, facilitate energy transfers, and ensure that all transactions are secure, transparent, and recorded accurately.

Cryptocurrency Transactions

Given the innovative nature of the UHEVsA model, cryptocurrency will be integrated into the mobile app to serve as the medium for energy transactions. This approach simplifies the payment

process for energy exchanges by removing the need for intermediaries and traditional payment systems. Cryptocurrency will enable quick and secure transactions between participants, with the app handling all necessary currency conversions and transaction fees.

By utilizing cryptocurrency, the app will enhance transparency and enable decentralized energy transactions, which is a key feature of the UHEVsA model. Each energy transaction will be recorded in a decentralized ledger, making it easily auditable and transparent for all parties involved. This system ensures that energy exchanges are fair, and participants can track their energy transactions in real time.

User Alerts and Notifications

To improve user engagement and facilitate energy management, the mobile app will include a notification system that provides users with important alerts about their energy consumption, generation, and storage levels. The app will notify users about potential energy shortages or surpluses and suggest optimal times for energy consumption based on availability.

Additionally, the app will send alerts regarding energy pricing, changes in energy availability, and opportunities for users to adjust their energy usage or contribute energy to the local grid. For example, users may receive notifications about energy price fluctuations, encouraging them to optimize their consumption to take advantage of lower rates during off-peak hours.

Furthermore, the notification system will alert users when their energy reserves are low, prompting them to either generate more energy or request energy from the grid or other users within the network. This system of real-time alerts will help users manage their energy consumption efficiently and ensure that they remain within their energy limits.

Integration with the UHEVsA System

The mobile application will seamlessly integrate with the broader UHEVsA system, ensuring that data from various energy sources (solar panels, wind turbines, batteries, EVs) is collected and processed centrally. The app will sync in real-time with the energy generation and storage systems, ensuring accurate and up-to-date information on energy usage, generation, and transfers.

The integration of the app with the broader UHEVsA network will allow users to interact with the energy system more efficiently, making energy sharing and distribution seamless across households, businesses, and EVs. By leveraging advanced technologies such as blockchain, the app can also ensure the transparency and security of energy transactions, further enhancing user confidence and participation in the decentralized energy system.

The mobile app will serve as a central hub for managing energy generation, consumption, and

distribution within the UHEVsA system. It will offer real-time monitoring, support energy exchanges, enable cryptocurrency transactions, and provide useful alerts to users. The app's integration with the UHEVsA model will empower users to actively participate in the decentralized energy system, contributing to the overall sustainability and resilience of the network.

3.2.2. App Integration with UHEVsA

The integration of the mobile application with the UHEVsA system is essential to ensure the smooth operation of the decentralized energy network. The app will serve as a centralized platform, allowing users to monitor, manage, and interact with the various components of the UHEVsA model, including energy production from renewable sources such as solar and wind, storage capacities (batteries), and electric vehicles (EVs).

Seamless Integration

The mobile app will be fully integrated into the UHEVsA system, offering a unified platform for users to view and control energy production, consumption, and storage. This integration will allow for real-time monitoring of the energy generation from solar panels, wind turbines, and the storage levels in batteries and EVs, all from one interface. The app will act as the central hub for managing all decentralized energy components, which aligns with the UHEVsA model's objective of operating independently from centralized grids. By enabling smooth interactions between various components, the app will ensure that energy flows efficiently throughout the system.

Transparency and Efficiency

A key feature of the mobile app will be its ability to promote transparency in energy transactions. By integrating the app with the UHEVsA system, users will have access to detailed, transparent data regarding energy exchanges, consumption patterns, and stored energy levels. This transparency will help build trust among users, ensuring that they have confidence in the system's integrity. Additionally, access to this data will enable better decision-making, both at the individual level and across the broader network. Optimized energy management can be achieved when users understand their consumption and generation patterns, helping them make informed decisions about energy use and trading.

Optimization Features

To improve the efficiency of energy use, the app will include optimization features, such as demand response tools. These tools will allow users to adjust their energy consumption based on real-time energy availability and the current status of renewable energy generation. For example, when

energy reserves are low, the app will send alerts to users, prompting them to either reduce consumption or shift their usage to times when renewable generation is at its peak. Similarly, the app will help users take advantage of periods when renewable energy generation exceeds demand by encouraging energy storage or energy sharing with others in the network. These optimization tools will ensure that energy is used efficiently, reducing reliance on stored energy and external energy sources.

User Interface and Accessibility

The mobile app will be designed with a user-friendly interface to ensure that all users – whether they are households, businesses, or EV owners – can easily navigate the system. The interface will feature clear, visual representations of energy consumption, generation, and storage. Users will be able to quickly view their energy balance and monitor the status of their solar panels, wind turbines, and batteries. The app will also provide simple tools for managing energy storage and distribution, enabling users to make adjustments as needed. The goal is to provide an intuitive experience, ensuring that even those without a technical background can effectively use the app to manage their energy systems and participate in energy exchanges.

Scalability and Flexibility

In anticipation of future developments in renewable energy technologies and energy markets, the app will be designed with scalability and flexibility in mind. As the UHEVsA model grows and evolves, the app will be able to support new upgrades, such as the integration of additional renewable technologies (e.g., solar or wind innovations), new storage solutions, or changes in the energy market. This scalability will ensure that the app remains relevant and useful, even as the system expands to accommodate more households, businesses, or energy users.

The integration of cryptocurrency for energy transactions adds an innovative layer to the app, making energy exchanges faster, more transparent, and more secure. Cryptocurrency will enable peer-to-peer energy trading, reducing reliance on traditional financial systems. This decentralization, coupled with the app's optimization tools and scalability, will help create a resilient, self-sustaining energy network that is capable of functioning efficiently, even in times of crisis.

The mobile app is a vital component of the UHEVsA system, offering users an efficient and intuitive platform for monitoring and managing their energy use, optimizing energy consumption, and participating in decentralized energy exchanges. The integration of the app with the broader UHEVsA system will support the goal of creating a resilient, self-sustaining energy network that can operate independently of centralized grid systems, particularly during times of infrastructure failure. The app's functionality, combined with cryptocurrency integration and the potential for future upgrades, will

play a crucial role in enhancing the overall efficiency, transparency, and sustainability of the UHEVsA system.

3.3. Legal Framework and Recommendations

3.3.1. Current Regulations

Overview of Existing Ukrainian Energy Laws:

The energy landscape in Ukraine is regulated by several laws, each contributing to the development of the energy sector, but often with a focus on centralized systems. The most relevant of these laws are discussed below:

The Law on Alternative Energy Sources:

This law is foundational in promoting the development of renewable energy in Ukraine, setting the principles for renewable energy generation. It includes mechanisms such as the green tariff, which provides financial incentives for generating renewable energy from sources like solar, wind, and biomass. While this law has played a significant role in encouraging renewable energy, it primarily supports large-scale renewable projects connected to the national grid. As such, it may need updates or amendments to better accommodate small-scale, decentralized systems like the UHEVsA model, where households, businesses, and vehicles can generate and store energy independently.

The Law on the Electricity Market:

This law governs the operation of the electricity market in Ukraine, including provisions for liberalization, market competition, and the integration of renewable energy into the national grid. However, it predominantly addresses the needs of centralized energy production and distribution. While it provides a clear regulatory framework for large energy producers and centralized systems, it may not fully support the goals of decentralized systems like UHEVsA, which aims to operate without reliance on the national grid and instead foster independent, local energy production and consumption. This gap may present challenges for the UHEVsA model, which requires a more flexible regulatory environment that accommodates autonomous, small-scale energy systems.

The Law on Energy Efficiency:

This law focuses on improving energy efficiency across various sectors, including residential, industrial, and transport. It includes measures for enhancing energy efficiency, such as energy audits, standards for energy performance, and promoting the use of energy-saving technologies. However, the law is largely oriented toward improving efficiency in traditional, centralized systems. To support

decentralized energy solutions, including systems like UHEVsA, the law may need to evolve to incorporate the role of energy storage systems, such as batteries, and decentralized energy production, like solar panels and wind turbines. These elements are essential to achieving energy efficiency in the context of autonomous energy networks.

Impact on Decentralized Energy Systems:

While these laws provide a solid foundation for renewable energy development, they are primarily geared toward supporting centralized energy systems and their integration with the national grid. This focus on centralization presents a challenge for decentralized energy models like UHEVsA, which envision households, businesses, and electric vehicles (EVs) as independent energy producers and consumers. For UHEVsA to succeed, some aspects of the current legal framework will need to be revisited or revised to support the autonomy of these systems.

In particular, the legal framework should allow for energy generation, storage, and distribution at the local level, providing clear guidelines for peer-to-peer energy trading, decentralized energy storage, and self-sufficiency in energy consumption. This could involve creating new regulations for decentralized energy exchanges, enabling households and businesses to engage in energy sharing and trading in a regulated environment. Furthermore, to facilitate the integration of electric vehicles as energy storage and distribution units, the regulatory framework should include provisions for vehicle-to-grid (V2G) technology and the role of electric vehicles in contributing to the energy grid.

The existing laws could be strengthened to recognize the potential of decentralized energy systems, encouraging their growth through appropriate policy adjustments and regulations that cater to small-scale producers. This will not only enable the success of the UHEVsA model but also contribute to broader energy resilience and sustainability goals.

3.3.2. Regulatory Challenges and Gaps

In this section, we discuss the regulatory challenges and gaps that may hinder the adoption of decentralized energy systems such as UHEVsA, focusing on key issues related to current laws, grid infrastructure, and market dynamics in Ukraine.

Regulatory Hurdles:

The existing regulatory framework in Ukraine primarily focuses on large-scale energy production and grid integration, with little regard for decentralized, small-scale energy systems like UHEVsA. Current laws do not sufficiently address the specific needs of distributed generation systems, including energy storage, peer-to-peer energy trading, and mobile energy management via electric vehicles

(EVs). As a result, the legal environment presents challenges for the smooth integration and operation of decentralized systems like UHEVsA, which require more flexible and innovative regulations.

Moreover, licensing and permitting processes for small-scale energy producers – such as households using solar panels or wind turbines – are often cumbersome and not suited to the speed and flexibility that the UHEVsA model demands. In many cases, these processes may be overly complex, requiring multiple approvals, which could significantly delay the implementation of decentralized energy systems. Simplifying and streamlining these procedures will be essential to the success of decentralized models like UHEVsA.

Grid Infrastructure Limitations:

Ukraine's current grid infrastructure is designed with centralized generation in mind, which limits its ability to support decentralized systems. UHEVsA's goal to operate independently from the central grid during crises may be obstructed by regulatory requirements that are overly tied to the existing grid structure. This presents a major challenge, as UHEVsA depends on the autonomy of local energy production and consumption, without relying on centralized grid infrastructure.

The current grid is also ill-equipped to accommodate the integration of electric vehicles (EVs) and energy storage solutions, which are central to the UHEVsA model. These systems require bidirectional energy flows – where energy can be both sent to and drawn from the grid or local systems. The lack of infrastructure to support these bidirectional flows may hinder the ability of UHEVsA to operate efficiently, particularly in situations where energy sharing between households, businesses, and EVs is crucial.

Market Dynamics:

The market dynamics in Ukraine are not yet fully conducive to decentralized energy systems. Traditional electricity pricing models tend to favor centralized energy generation, which may not be favorable for decentralized energy transactions or peer-to-peer energy trading. UHEVsA, which relies on local energy generation and decentralized exchanges, needs to operate in a market where pricing models are more flexible and support energy sharing among consumers, rather than traditional centralized utility-based pricing.

Additionally, the lack of a legal framework for cryptocurrency-based energy transactions may present another challenge. UHEVsA plans to integrate cryptocurrency as a medium for energy transactions, which would allow for seamless, decentralized payments. However, the absence of legal provisions for such transactions could hinder the development of the digital payment systems necessary for UHEVsA's operation. The regulatory framework needs to evolve to accommodate

cryptocurrency payments, ensuring the legality and security of these transactions.

In summary, while Ukraine has made significant strides in supporting renewable energy, the current regulatory framework is more focused on centralized systems and does not fully support decentralized energy models like UHEVsA. Addressing the regulatory hurdles, grid infrastructure limitations, and market dynamics will be essential for ensuring that UHEVsA can be implemented successfully, allowing for the development of a resilient and decentralized energy system in Ukraine.

3.3.3. Recommendations for Policy Changes

In order to facilitate the successful implementation and scaling of decentralized energy systems like UHEVsA, several policy adjustments are necessary. The following recommendations outline key areas where changes in Ukraine's legal and regulatory frameworks could accelerate the adoption of decentralized energy solutions and support the UHEVsA model.

Policy Adjustments to Support Decentralized Energy Systems:

1. **Tax Incentives and Subsidies:** The Ukrainian government can play a crucial role in promoting the adoption of decentralized energy systems by offering tax breaks or subsidies for households and businesses that install renewable energy technologies, such as solar panels, wind turbines, and energy storage systems. These incentives can help reduce the initial financial burden of adopting clean energy solutions. Additionally, promoting electric vehicle (EV) adoption through incentives would help further integrate EVs into the UHEVsA system, where they serve as mobile energy storage units. Supporting EVs in this way would also reduce the reliance on the central grid and enhance the resilience of the overall energy system.

2. **Regulatory Updates:** The legal framework in Ukraine must be updated to create a clearer and more flexible framework for decentralized energy systems like UHEVsA. This includes developing new laws or revising existing ones to accommodate the specific needs of small-scale energy producers. Regulations should focus on streamlining processes such as permitting for energy generation systems and addressing the legal complexities of peer-to-peer energy trading, which is central to the UHEVsA model. Additionally, legislation should account for the growing role of electric vehicles as energy storage systems, facilitating the integration of technologies like Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H).

3. **Support for EV Integration and Energy Storage:** Policies should actively support the integration of electric vehicles into the broader energy system. This could include creating clear guidelines for V2G and V2H technologies, which enable energy to be transferred from vehicles back

into homes or the grid. In addition, energy storage solutions – vital for balancing intermittent renewable energy generation – should be recognized as a critical component of the energy infrastructure, with regulatory frameworks that facilitate their adoption. Policies that incentivize both residential and commercial energy storage would greatly enhance the UHEVsA model's ability to function efficiently and autonomously, especially in times of grid instability.

4. **Reforming Grid Integration Policies:** While the UHEVsA model is designed to operate independently of the central grid during crises, there should be regulatory provisions that allow for seamless integration with the national grid when necessary. Decentralized energy systems, such as UHEVsA, should have the flexibility to connect with the grid without excessive bureaucratic hurdles. This could include creating flexible grid connection rules that allow decentralized systems to either operate autonomously or synchronize with the national grid when required. Such policies would provide the option to “plug in” to the grid for backup or during times of high demand, ensuring that the decentralized systems can continue to function efficiently while contributing to national energy security.

5. **Encouraging Innovation and R&D:** In order to support the growth and scalability of decentralized energy systems like UHEVsA, the government should encourage innovation in renewable energy technologies, energy storage, and energy distribution. Providing grants and funding for research and development (R&D) can help create more efficient and cost-effective solutions that better suit the needs of decentralized networks. Promoting collaboration between academia, industry, and government will be crucial in driving innovation and enabling the integration of cutting-edge technologies into the UHEVsA system.

The current legal framework in Ukraine provides a foundation for the development of renewable energy, but it needs significant updates to fully accommodate decentralized systems like UHEVsA. To ensure the widespread adoption of such systems, it is essential to introduce tax incentives, revise regulations for small-scale energy producers, and support EV integration and energy storage technologies. Additionally, updating grid connection rules and creating flexible market structures will be vital to the success and sustainability of decentralized energy solutions. A modernized and adaptive legal environment will unlock the full potential of the UHEVsA model, ensuring it can provide reliable, resilient, and sustainable energy solutions, especially during crises or emergencies

CONCLUSIONS

Summary of Findings

The analysis of the UHEVsA model has provided important insights into its potential as a primary energy source during crises when centralized grids are compromised. The key findings from this project are as follows:

The UHEVsA model, which relies on renewable energy sources such as solar and wind, as well as energy storage through batteries, has been found to be technically feasible. The integration of electric vehicles (EVs) as mobile energy storage units further enhances the system's flexibility and resilience. The calculations for energy generation, storage, and distribution demonstrate that UHEVsA can meet the basic energy needs of households and businesses even during power outages or grid failures. By using EVs, which can store energy and supply it back to the system, the model offers an innovative solution to improve energy security, particularly during times of grid instability.

From an economic perspective, although the initial investment in renewable energy systems, EVs, and storage solutions is substantial, the long-term savings are significant. The reduction in reliance on centralized grids and the ability to operate independently during crises make UHEVsA economically viable. The cost analysis shows that, when compared to the costs of rebuilding and maintaining centralized infrastructure, UHEVsA can be a cost-effective alternative, particularly when considering the resilience it provides in crisis situations. In the long run, the ongoing savings from reduced energy costs and increased energy security outweigh the initial investment required for the UHEVsA system.

The regulatory landscape in Ukraine presents several challenges to the full implementation of decentralized energy systems such as UHEVsA. Existing laws and policies are primarily focused on centralized energy systems, and they fail to fully address the needs of small-scale, decentralized energy production, peer-to-peer energy trading, and the integration of EVs and energy storage technologies. The current regulatory framework will need to be updated to support decentralized solutions and encourage the adoption of EVs and energy storage systems. Without these updates, the potential for UHEVsA to scale effectively will be limited. A more flexible and supportive regulatory environment is crucial for fostering the widespread adoption of decentralized energy systems and enabling their integration into the broader energy landscape.

Implications for Future Research

While this project has provided a comprehensive analysis of the UHEVsA model, there are several areas where further research is required to fully realize its potential and improve its effectiveness.

One area for future research is improving the integration of renewable energy sources, storage systems, and electric vehicles (EVs) into a cohesive decentralized network. The current analysis focused on individual components, but a more in-depth examination of how these elements can interact seamlessly is necessary. Research into advanced energy management systems, smart grids, and optimization algorithms could significantly enhance the efficiency and reliability of such systems, ensuring that energy generation, storage, and distribution are balanced and adaptable in real-time.

Another important research direction involves exploring alternative energy storage technologies. While lithium-ion batteries are currently the most commonly used storage solution, there is potential for more efficient and sustainable technologies. Solid-state batteries and hydrogen storage, for example, offer advantages such as improved efficiency, longer lifespans, and reduced environmental impact. Further studies in this area could help identify more effective energy storage methods, making decentralized systems like UHEVsA more reliable and sustainable in the long term.

The social impacts of decentralized energy systems like UHEVsA also warrant further research. These systems have the potential to promote energy equity and provide greater access to clean energy, especially in underserved or rural areas. Understanding the broader social implications of UHEVsA, such as how it might influence local communities, create jobs, or stimulate economic opportunities, is crucial for ensuring its acceptance and success. Research into these social dynamics will also help address potential challenges related to equity and fairness in energy distribution.

Additionally, as UHEVsA is designed to provide power during crises, future research should focus on resilience modeling and the simulation of various crisis scenarios. Investigating how the UHEVsA system can maintain reliability under different conditions, such as natural disasters, power outages, or geopolitical conflicts, would help refine the system's design. This could ensure that it remains a dependable energy solution, even during extreme circumstances, and can operate effectively under a variety of crisis scenarios.

Final Remarks

The UHEVsA model presents a promising solution for decentralized energy generation, particularly in regions facing infrastructure instability or unreliable centralized grids. Through the integration of renewable energy sources such as solar and wind, energy storage technologies, and

electric vehicles (EVs) as mobile storage units, UHEVsA offers the potential to create resilient, self-sustaining energy systems capable of operating independently during crises.

The analysis conducted in this project has highlighted the technical feasibility, economic viability, and regulatory challenges associated with implementing UHEVsA. It is clear that, while the model offers substantial benefits in terms of energy security, particularly for households and businesses, there are significant regulatory and policy barriers that need to be addressed. These challenges must be met with the adoption of supportive laws and incentives to promote the widespread integration of decentralized energy systems and facilitate the use of EVs and energy storage solutions.

Despite these obstacles, the potential of UHEVsA to mitigate energy insecurity, especially in crisis situations, cannot be overstated. It offers a viable alternative to traditional centralized grids, with the added benefits of flexibility, scalability, and resilience. By empowering local communities with the ability to generate, store, and exchange energy, UHEVsA can play a key role in improving energy equity and access, particularly in rural or underserved areas.

As research and technological advancements continue, it is likely that decentralized energy systems like UHEVsA will become increasingly viable and efficient. Future work should focus on optimizing the integration of renewable technologies, exploring alternative storage solutions, and assessing the broader social impacts of decentralized systems. These efforts will be crucial in ensuring that UHEVsA, and similar models, can provide a stable and sustainable energy future for communities across the globe.

The UHEVsA model represents a significant step towards achieving energy resilience and security, especially in regions with compromised infrastructure. With further research, policy support, and technological advancements, it has the potential to revolutionize how we think about energy generation and distribution in the future.

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