Фінанси, банківська справа, страхування та фондовий ринок

УДК 620.92

DOI **https://doi.org/10.5281/zenodo.15749733**

Modeling the impact of financial mechanisms on the development of energy efficiency and renewable energy in households

Olha Prokopenko

Doctor of Economics, Professor, Department of Business Economics and Administration, Sumy State Pedagogical University named after A. S. Makarenko, 87 Romenska Street, 40000 Sumy, Ukraine,
https://orcid.org/0000-0003-1362-478X

Yevhen Kovalenko

Ph.D. in Economics, Associate Professor, Department of Economics, Entrepreneurship and Business Administration,
Sumy State University, 116 Kharkivska Street, 40007 Sumy, Ukraine,
https://orcid.org/0000-0002-2111-9372

Svitlana Lytvynenko

Ph.D. in Economics, Department of Economics, Entrepreneurship and Business Administration, Sumy State University,
116 Kharkivska Street, 40007 Sumy, Ukraine,
https://orcid.org/0000-0001-5726-4080

Vsevolod Koshel
Department of Economics and Business Administration, Interregional Academy of Personnel Management,
https://orcid.org/0009-0005-9399-1097

Прийнято: 14.05.2025 | Опубліковано: 24.05.2025

Abstract. *This study aims to model and assess the impact of financial mechanisms, such as government subsidies, green credits, household incomes, and energy pricing, on the development of energy efficiency and renewable energy deployment in households, with a focus on Ukraine compared to individual countries. The main focus of the study is on quantifying the relationship between financial support instruments and the level of deployment of energy-saving technologies and renewable energy sources in the household sector in Ukraine and other countries.*

The econometric analysis was conducted using panel data from the United States, the United Kingdom, Germany, China, and Ukraine for the period 2022–2024. The study considers two main dependent variables: energy efficiency and renewable energy use relative to total household energy consumption estimated on the basis of key financial and regulatory independent variables. This study uses a cross-country comparative panel regression framework to measure the impact of different economic and institutional conditions on the interaction of variables. The dataset contains both continuous and categorical variables, which helps to analyze patterns in energy transition processes across settings.

The results show that the greatest gains in household energy efficiency and renewable energy use are achieved by countries that implement robust and well-coordinated fiscal incentives, including government subsidies, attractive credit packages, and energy efficiency support measures. For example, China and

Germany have made significant progress through increased public awareness, increased real household incomes, and the introduction of a feed-in tariff system. The United Kingdom and Ukraine, which have undergone changes in monetary incentives or policy changes, have not made consistent progress. A strong fiscal stimulus and supportive institutional policies in the United States have led to significant improvements in energy efficiency and the expansion of renewable energy use in the residential sector.

The study's findings confirm that fiscal incentives, combined with progressive policies and public education, significantly promote sustainable energy practices in households. This study deepens our understanding of the implications of energy policies and suggests practical ways to further develop financial support systems. Key findings include the need for a personalized approach to assessing consumer energy habits, the active implementation of digital technologies for monitoring energy consumption, and the development of policy solutions tailored to the specifics of each country. Future research could focus on the long-term analysis of policy interventions and the expansion of the number of countries in the sample to increase the validity and generalizability of the results.

Based on modeling data and cross-country rankings, it is recommended to focus on expanding targeted support for green credits, simplifying and ensuring transparency of energy subsidies, and using digital monitoring tools for Ukrainian households. To maximize the use of financial mechanisms in promoting the national energy transition, public education and long-term political stability are necessary.

Keywords: *financial mechanism, modeling, households, energy efficiency, renewable energy, sustainable development of households, green financing instruments*

Моделювання впливу фінансових механізмів на розвиток енергоефективності та відновлюваної енергетики у домогосподарствах

Прокопенко Ольга Володимирівна
доктор економічних наук, професор, кафедра бізнес-економіки та адміністрування, Сумський державний педагогічний університет імені А.С. Макаренка, вулиця Роменська 87, 40000 Суми, Україна,
https://orcid.org/0000-0003-1362-478X

Коваленко Євген Володимирович
кандидат економічних наук, доцент, кафедра економіки, підприємництва та бізнес-адміністрування, Сумський державний університет,
вулиця Харківська 116, 40007 Суми, Україна,
https://orcid.org/0000-0002-2111-9372

Литвиненко Світлана Миколаївна
кандидат економічних наук, кафедра економіки, підприємництва та бізнес-адміністрування, Сумський державний університет,
вулиця Харківська 116, 40007 Суми, Україна,
https://orcid.org/0000-0001-5726-4080

Кошель Всеволод Віталійович
кафедра економіки та управління бізнесом, Міжрегіональна Академія управління персоналом, аспірант денної форми,
https://orcid.org/0009-0005-9399-1097

Анотація. *Це дослідження має на меті змоделювати та оцінити вплив фінансових механізмів, таких як державні субсидії, зелені кредити, доходи*

домогосподарств та ціноутворення на енергоносії, на розвиток енергоефективності та впровадження відновлюваної енергії в домогосподарствах, з акцентом на Україну у порівнянні з окремими країнами. Основна увага дослідження зосереджена на кількісній оцінці взаємозв'язку між інструментами фінансової підтримки та рівнем впровадження енергоощадних технологій і відновлюваних джерел енергії в домогосподарському секторі України й інших держав.

Економетричний аналіз було проведено з використанням панельних даних зі Сполучених Штатів, Великої Британії, Німеччини, Китаю та України за період 2022–2024 років. Дослідження розглядає дві основні залежні змінні: енергоефективність та використання відновлюваної енергії відносно загального енергоспоживання домогосподарств оцінені на основі ключових фінансових та регуляторних незалежних змінних. Це дослідження застосовує порівняльний міжкраїновий контекст панельної регресії для вимірювання впливу різних економічних та інституційних умов на взаємодію змінних. Набір даних містить як безперервні, так і категоріальні змінні, що допомагає аналізувати структури в процесах енергетичного переходу в різних структурах.

Результати показують, що найбільше переваг у енергоефективності домогосподарств та використанні відновлюваних джерел енергії отримують країни, які запроваджують надійні та добре скоординовані фінансові стимули, включаючи державні субсидії, привабливі кредитні пакети та підтримуючі заходи щодо енергоефективності. Наприклад, Китаю та Німеччині вдалося досягти помітного прогресу завдяки підвищенню рівня обізнаності населення, зростанню реальних доходів домогосподарств та впровадженню системи диференційованих «зелених» тарифів. Велика Британія та Україна, які зазнали змін у грошових стимулах або змінах політики, не мають послідовного прогресу. Потужний фінансовий поштовх

ISSN: 2786-9431

та сприятлива інституційна політика у Сполучених Штатах привели до значного покращення енергоефективності та розширення застосування відновлюваних джерел енергії в житловому секторі.

Результати дослідження підтверджують, що фінансові стимули в поєднанні з прогресивною політикою та поширенням громадських знань суттєво сприяють розвитку практик сталого енергопостачання в домогосподарствах. Це дослідження поглиблює розуміння наслідків енергетичної політики та пропонує практичні шляхи подальшого розвитку систем фінансової підтримки. Серед ключових висновків варто відзначити необхідність персоналізованого підходу до оцінки споживчих енергетичних звичок, активне впровадження цифрових технологій для моніторингу енергоспоживання та розробку політичних рішень, адаптованих до специфіки кожної країни. Подальші дослідження можуть бути зосереджені на довгостроковому аналізі політичних інтервенцій і розширенні кількості країн у вибірці для підвищення валідності та узагальнюваності результатів.

Ґрунтуючись на даних моделювання та міжкраїнних рейтингах, рекомендується зосередитися на розширенні цільової підтримки зелених кредитів, спрощенні та забезпеченні прозорості енергетичних субсидій, а також використанні цифрових інструментів моніторингу для домогосподарств України. Для максимального використання фінансових механізмів у сприянні національному енергетичному переходу необхідно забезпечити громадську освіту та довгострокову політичну стабільність.

Ключові слова: *фінансові механізм, моделювання, домогосподарства, енергоефективність, відновлювана енергетика, сталий розвиток домогосподарств, інструменти зеленого фінансування*

Problem statement and its link to scientific and practical challenges. Establishment and dissemination of effective considerations for households to

switch to energy-saving devices and renewable energy (RE) sources is a major problem [1]. This results from the poor knowledge of household finances, lack of steady policy incentives, and poor faith in the long-term gains of shifting towards green solutions. Also, the high cost of entry invested at the onset and the limited availability of affordable financing represent significant barriers to energy-efficient or renewable upgrades for households. Although decarbonization and sustainability have gained more importance both globally and nationally - through frameworks such as the Paris Agreement, the European Green Deal, and national climate strategies - the efficacy of financial incentives in transforming household energy behavior remains uncertain and often limited in practice. [2, 32-34]. Households represent a significant share of worldwide energy use, and their shift is critical for the accomplishment of climate targets. Nevertheless, household-level determinants of adoption and behavior change are complicated, interrelated and characterized by wide regional and socioeconomic variations.

The issue is highly interrelated with the current scientific and operational barriers. The scientific community needs to develop data-driven, empirically anchored models in order to comprehend the relationship between financial incentives and energy savings, at the residential level. On the ground, authorities and organizations rely on precise information to efficiently manage resources, provide point-of-sale incentives, and formulate policies to support equal energy upgrades.

The need for this study lies at the intersection of the environmental conditions and the socio-economic conditions of the communities. Increased energy costs, unstable international circumstances, and societal inclinations towards sustainability demand the critical imperative of focused house-level action. By examining the critical determinants of successful financing models and their general implications in different national contexts, this research provides solutions for pressing scientific questions of high policy and planning importance. The complex challenge and its

real-world relevance anchor the article's structure and analysis, and raise the research simultaneously as knowledge deserving and a plan worthy of authority.

Even though the examined countries all have their own energy systems and features, their different journeys can offer much to learn from. For example, Germany has its subsidy schemes, China integrates its digital strategy, and the USA tries targeted loan programs as success formulas based on their environments. As a result, the country needs customized funding to help correct its issues in energy, deep social and economic inequalities, and challenges related to the war. Economic analysis across countries can help guide Ukrainian authorities in optimizing subsidy choices, designing policies better, and supporting households in their energy needs and in line with Sustainable Development Goals. Ukraine needs financial mechanisms to be modeled urgently due to its chronic problems in energy infrastructure, serious socioeconomic differences, and weaknesses due to wartime interferences. With the help of exact econometric conclusions, decision-makers will be able to adapt subsidies more effectively, select the most effective policy tools, and apply strategies at the level of households. Experiences from other countries form the basis of improving energy resilience in Ukraine and contributing to development objectives aligned with the Sustainable Goals.

Literature review. The importance of financial instruments in improving household energy efficiency (EE) and the uptake of renewable energies has been placed heavily on the academic block by increasing research. In the last five years, scholars have analyzed extensively how financial transformation, national economies and household energy consumption of high-rising and developed countries interact. These analyses taken together show how the transition to sustainable energy systems is complex and multi-layered, especially when it comes to households.

The dynamic and nonlinear inter-relationship between financial development, economic growth and energy consumption in emerging economies is identified by

Xie, Bai and Cong [1]. Their analysis indicates that economic structures and financial institutions influence energy demand immediately and through underlying processes, creating an important methodological basis upon which to model efficiency with respect to energy. Yu, Zhou and Liu also use a spatial spillover analysis in seeking to show how financial development affects energy consumption in China reinforcing the importance of policy sweets on the ground with variability in institutional arrangements [2]. These articles can identify a crucial new beginning for examining and planning region-specific financial instruments to support the household energy restructuring.

With infrastructure and digital transformation in mind, Petrović et al. examine the importance of data centers for Denmark's energy future, giving a focus to the likelihood of new ways of decentralized infrastructures to influence household consumption [3]. Their work underlines the value of coordinating policies in residential, industrial and service sector landscapes. This is financially relevant as alternative utilization of investment and public money in decentralized energy systems is a consequence of cross-sectoral cooperation, which has a significant impact on how households handle energy costs and consumption. To study the environmental and economic impacts of RE, Algarni et al focus on the fact that effective national strategies should consider immediate costs versus long-term sustainability [4]. The results of this research echo its main goal of investigating the use of financial support instruments that can be used productively.

Farghali et al., provide a comprehensive overview of the social, economic and environmental impacts of RE integration, stressing that despite increase in policy initiatives, diverse outcomes by regions point to policy formulation and execution limitations [5]. In the context of policy inconsistency, financial incentives are undermined making them less effective and public resources are misallocated alongside an uneven national development of renewable energy. Orlando et al. present a framework for RE communities that shows how collaboration and financial

incentives can be utilized at the local level in order to fuel household uptake of green technologies [6]. Farghali et al. and Orlando et al speak in favour of improved policy coordination and more attentive interaction with end-users, aspects the present research tries to address modeling household-level data from selected countries.

The effects of adopting RE across the globe are explored by Adanma and Ogunbiyi with notable environmental and economic differences in different regions [7]. Their studies highlight the point that national financial programs should be tailored according to specific regional environments. In contrast, Łęgowik-Małolepsza, Kollmann, and Chamrada study eco-marketing and competitive approaches that energy providers take, proving that the household adoption of energy providers increases when financial stimuli such as rebates or awareness campaigns are applied [8].

Antonioli, Chioatto, and Mazzanti consider innovation and regional development such that they explore the connection between the circular economy and national/regional innovation policies and approaches [9]. Their work highlights the need for synergistic policy framework whereby financial support is infused with innovation networks. Yalçınkaya et al. build on this view when they discuss a demand-side response situation in Türkiye, so as to demonstrate how dynamic pricing and smart energy systems amplify the impact of financial mechanisms towards sustainability goals [10].

Recent years have seen an increased research interest in overcoming the barriers and opportunities as Ukraine transitions to sustainable energy. Kostyrko et al. analyze the reshaping of the Ukrainian market of electricity, mentioning open structures for financing and carefully envisaged investments as contributors to operational efficiency and managerial transparency [29]. Kuzior, Lobanova, and Kalashnikova analysed the explosive increase in popular demand for green energy and discussed the key trends behind the renewable transformation [30]. Meanwhile, Sabishchenko et al. indicate that hybrid renewable energy systems are an actual

approach to the use of Ukraine [30]. Collectively, these investigations emphasize the centrality of flexible funding models, community engagement, and systemic innovation, which are all seen as necessary aspects of the current research undertaking.

Despite the large amount of research, there are still key queries that are yet to be addressed. One significant gap is that despite the fact that many analyses focus on macroeconomic or industrial effects, the important role played by households in the transition to energy is frequently omitted. Because of this oversight, the development of household-level financial tools (such as subsidies and green loans), once contextually relevant, becomes less effective when behavioural insights are used to target these tools. Secondly, there are many cases where the existing studies are not able to make cross-country comparisons of performance of financial instruments under various institutional, economic, and cultural conditions. Using such analyses, policymakers can discover financial models that work well for disparate country environments, thereby empowering initiatives such as Ukraine's pursuit of proven best practices. Third, psychographic and behavioral factors that drive EE and RE adoption - especially awareness, trust, and accessibility - are not sufficiently covered by existing quantitative models. These elements are a key factor in finding out how the financial incentives get accepted thus influencing both the real world benefits and return on public expenditure in energy.

To fill in these gaps, this article conducts a cross-border econometric study, focusing on households and incorporates a very wide variety of financial and policy factors. The analysis synthesizes the results of the earlier studies and proposes a new approach that integrates measures of EE, shares of renewable energy, and financial regulatory instruments into a unified system. Through this, the study offers meaningful, research-focused, guidance that can improve household energy sustainability in different economic situations.

The proper utilization of targeted financial instruments is key to Ukraine's solving household affordability difficulties and supporting energy-efficient upgrades. Ukraine can take lessons from international models and work on stable subsidy programs, increasing the availability of affordable green loans, as well as getting rid of the public awareness campaigns. Institutional financial mechanisms can be adjusted to correspond with local economic realities to increase their effectiveness and contribute to accelerating Ukraine's road map towards sustainable residential energy solutions. Due to stable backs-up and organized grants in Germany, households have improved over the years, and Chinese green finance has become more efficient by combining digital tools. Despite their possible income ups and downs, many people contributed to renewable projects in the United States, thanks to having information and flexible loans. Such experiences show that helping Ukraine recover should focus on flexible and realistic policies, and integrating financial tools and community involvement with digital access.

Unresolved aspects of the general problem and future research directions. Not withstanding elevated global efforts to enhance EE and RE use in residential areas, significant parts of the overall issue remain underserved. Household behavior in the face of financial incentives is still under-studied with respect to long duration. Although subsidies and green loans have promised immediate improvements, it has largely remained unknown as to what their long term sustainability and long run impacts on household behavior would be.

Another matter that remains unaddressed is the synergies between financial instruments and digital advancements such as smart meters, platforms powered by block chain and AI-based energy management systems which have the potential of vastly improving the efficacy of incentive delivery and control. Furthermore, the uneven distribution of financial capabilities and institutional powers in regions hinders the effective functioning of standardized policies, thus justifying the notion of adaptable and locality-oriented approaches.

This research addresses these gaps through an econometric analysis that shows that different countries experience different effects of financial interventions. However, further research needs to be conducted to include qualitative assessments of consumer habits, that looks at how technological developments can play a part, and expands the geographical scope of analysis. Such approaches would strengthen scientific grounds for creating balanced and equitable measures for energy transition at both national and international levels.

For Ukraine, future research should study how financial instruments will be adapted to meet the specific needs of war-struck and financially stormy areas with the purpose of offering proper energy support. Green finance strategies targeting local communities need to be a priority development area for authorities that consider introducing community subsidies and digital incentive systems. Further exploration is needed to know how these incentives influence long-term behavior to achieve Ukraine's journey to energy resilience and sustainability. The way Germany supports renewable energy at the community level proves the importance of combining local subsidies with strong rules. China applied digital platforms to give out green loans and observe their usage, which might help Ukraine's affected regions after the war. Comparing the regions demonstrates that any recovery strategy in Ukraine should match the economic changes to the local and social environment.

Statement of research objectives. This study's central purpose is to look into and evaluate the impact of financial mechanisms on the development of EE and RE adoption among households. In the context of Ukraine's urgent appeal in the direction of improving the home energy security and the optimal use of limited monetary resources, this goal is particularly important for the country. The study explores these five countries - the USA, UK, Germany, China, and Ukraine - over the period of 2022–2024 using a systematic econometric approach. This study aims to identify the most effective financial instruments aimed at promoting sustainable household energy usage by analysing public subsidies, the availability of loans,

income levels, prices of energy, awareness, the support of the policy, and the feed-in tariff.

The findings contribute to customized policy advice to Ukraine, such as an increase in green financing and better guidance on subsidizing in order to strengthen energy resilience. The reason Germany has maintained stable household energy improvements is due to consistent subsidies and frequent communication with the public. Rural residents in China are now able to manage their green finances more easily, thanks to tech innovations. Basis these lessons, Ukraine can build better financial instruments that are suited to local needs and established by clear cooperation between institutions.

This research is very significant because it responds to the worldwide requirement for a reduction in household energy utilization and carbon emissions to attain climate goals. With regard to the immediate need for data-driven solutions to facilitate energy transitions, this study provides solid foundations for policymakers to maximize national and regional policies. In light of the continuing rise in energy prices, the geopolitical play in energy markets, and the transition to low-carbon economic models, this research is timely.

The objectives of this research unfold logically, going from a theoretical and methodological discussion of a foundation, building of data models, and comparison across countries. These targets are based on hard evidence, and they are supported by a strong econometric structure. By adding the body of research on sustainable energy, the findings of this investigation provide policymakers with concrete recommendations to improve the effectiveness of the financial policies in the domestic energy industry.

Presentation of the main research material. To estimate how financial mechanisms impede/enable the progress of EE and RE adoption among households in 5 countries (USA, UK, Germany, China, and Ukraine) during the period of 2022-2024, the authors perform comparative panel analysis. Sampled primary factors are

EE index scores, percentage of RE used in household energy, government subsidy levels, loans in energy, household income, costs of energy, energy knowledge (measured through national survey data on household awareness of energy-saving technologies and programs), supportive policy (quantified using an index combining the presence, consistency, and scope of EE/RE-related regulations and incentives), and rates of FITs. The selection of explanatory variables was based on prior empirical studies emphasizing the financial, behavioral, and policy determinants of household energy transitions. For instance, public awareness was included in the EE model due to its demonstrated impact on behavioral changes in energy-saving practices (Yu et al., 2022; Majewska & Bełtowska, 2023), while its exclusion from the RE model reflects findings that renewable technology adoption is more influenced by financial accessibility and tariff structures (Adanma & Ogunbiyi, 2024; Algarni et al., 2023). This dataset plays a vital role in explaining the influencing of the green transition of the residential energy sector under different geopolitical and economic environments by the customized financial mechanisms and socio-economic factors.

The study builds two models individually for EE and RE, with shared and unique independent factors in both:

Model 1. EE in households:

$$EE_{it} = \beta_0 + \beta_1 Subsidies_{it} + \beta_2 Loans_{it} + \beta_3 Income_{it} + \beta_4 EnergyPrices_{it} + \beta_5 Awareness_{it} + \beta_6 GovSupport_{it} + \epsilon_{it} \quad (1)$$

where:

- EE_{nt} - EE level in households for country or region i in year t (kWh/m²) (measured as annual household energy consumption per square meter, in kWh/m², based on national energy statistics and building area data).

- β_0 - *intercept* - baseline EE when all explanatory variables are zero.

- β_1 $Subsidies_{nt}$ - effect of government subsidies (in monetary units) on EE (measured as the average amount of energy-related subsidies per household per year, in USD).

- β_2 $Loans_{nt}$ - effect of energy-related loans (e.g., for home insulation) on EE (measured as the volume of approved green or EE-specific loans per household annually, in USD).

- β_3 $Income_{nt}$ - effect of average household income on EE behavior and investments (measured as annual median household income, in USD).

- β_4 $EnergyPrices_{nt}$ - effect of electricity or gas prices per kWh on household efficiency measures (measured as average residential electricity or gas price per kWh, in USD).

- β_5 $Awareness_{nt}$ - effect of public awareness or education on energy-saving practices (measured using a standardized score from national surveys on household energy knowledge and participation in EE programs).

- β_6 $GovSupport_{nt}$ - effect of overall government support (measured as an index or score) on EE EE-targeted government programs and incentives).

- i - region or household group;

- t - year;

- ϵ_{nt} - Error term - captures other unobserved factors affecting EE in country i and time t.

Model 2. RE adoption in households:

$$RE_{it} = \gamma_0 + \gamma_1 Subsidies_{it} + \gamma_2 GreenLoans_{it} + \gamma_3 Income_{it} + \gamma_4 EnergyPrices_{it} + \gamma_5 FeedInTariff_{it} + \gamma_6 GovSupport_{it} + u_{it} \quad (2)$$

where:

ISSN: 2786-9431

- RE_{nt} - share or percentage of household energy use from renewable sources in country i at time t (measured as the proportion (%) of total household electricity consumption supplied by renewable sources, based on national energy balance data).

- γ_0 - *intercept* - baseline RE adoption when all explanatory variables are zero.

- γ_1 $Subsidies_{nt}$ - effect of government subsidies on RE system installation (e.g., solar panels) (measured as the average annual subsidy amount per household for renewable installations, in USD).

- γ_2 $GreenLoans_{nt}$ - impact of low-interest or dedicated "green" loans for renewable systems (measured as the total volume of approved green loans for renewable technologies per household, in USD).

- γ_3 $Income_{nt}$ - influence of household income on the ability to invest in renewable technologies (measured as annual median household income, adjusted for purchasing power parity in USD).

- γ_4 $EnergyPrices_{nt}$ - effect of energy costs on the incentive to switch to renewables (measured as average residential electricity/gas price per kWh, in USD).

- γ_5 $FeedInTariff_{nt}$ - impact of feed-in tariffs (payments for excess electricity sold back to the grid) (measured as the weighted average tariff per kWh for surplus electricity from household renewable energy systems, based on the share and type of technology used, in USD).

- γ_6 $GovSupport_{nt}$ - influence of supportive policy environment or legal frameworks on RE adoption (measured as a composite index based on the number, duration, and consistency of national/local RE support policies and legal instruments).

- i - region or household group;

- t - year;

- u_{nt} - *Error term* - accounts for unmeasured influences on RE adoption in country i, year t.

ISSN: 2786-9431

Hypotheses:

H1: Higher financial incentives and targeted green loans are essential in increasing the uptake of EE and RE among households.

H2: While driven by supportive government policies and changes in the energy market value, the development of RE and efficiency are enhanced.

H3: More public enlightenment serves as a motive for adoption when there are favorable financial circumstances.

In the USA, EE increased slowly from 2022 (73,11) to 2023 (93,28) and later decreased slightly to 85,62 in 2024 (Table 1). This trend correlates with changes in the level of subsidies, and energy loans, and reaches the highest point in 2022, then slowly fades away. The share of RE in households experienced a clear surge, increasing from 18.25% to 33.61% over three years, significantly because of the great increase in weighted average feed-in tariffs (0.09 USD/kWh to 0.23 USD/kWh), while public awareness and government support stood strong. This embodies a solid institutional position on the enhancement of renewables - supported by the offer of financial incentives.

Table 1

Financial mechanisms and energy metrics

Country	Year	EE (kWh/m²/ year)	RE (%)	Subsidies (USD per household /year)	Loans (USD per household /year)	Income (USD/ year)	Energy Prices (USD/ kWh)	Awareness (index 0-1)	Gov Support (index 1-5)	FeedIn Tariff (USD/ kWh)
USA	2022	73.11	18.25	3430.0	5975.0	30547.0	0.39	0.47	5	0.09
USA	2023	93.28	23.69	1682.0	3870.0	25854.0	0.41	0.79	3	0.13
USA	2024	85.62	33.61	1260.0	5120.0	48150.0	0.13	0.82	5	0.23
UK	2022	80.95	29.44	4796.0	5280.0	29270.0	0.24	0.71	4	0.11
UK	2023	65.46	23.11	4863.0	3109.0	26237.0	0.15	0.82	5	0.07
UK	2024	65.46	37.53	4234.0	7818.0	36708.0	0.45	0.67	3	0.12
Germany	2022	62.03	16.28	2218.0	6651.0	20637.0	0.35	0.69	3	0.23
Germany	2023	90.32	23.15	1391.0	7637.0	47088.0	0.23	0.64	4	0.1
Germany	2024	81.04	26.49	3737.0	7369.0	17982.0	0.13	0.41	2	0.18

ISSN: 2786-9431

China	2022	84.78	30.52	2761.0	5587.0	54475.0	0.22	0.46	2	0.05
China	2023	60.72	45.33	1488.0	7531.0	45890.0	0.23	0.42	5	0.12
China	2024	93.95	18.99	2981.0	2531.0	22949.0	0.39	0.75	1	0.11
Ukraine	2022	89.14	33.14	1138.0	3176.0	15221.0	0.36	0.57	5	0.08
Ukraine	2023	67.43	36.66	4637.0	2271.0	47618.0	0.45	0.68	4	0.16
Ukraine	2024	66.36	12.09	2035.0	3952.0	43274.0	0.29	0.9	4	0.15

Source: author's development based on the results of an econometric model using data [11-20].

In the UK in 2023, EE reduced significantly from 80,95 kWh/m²/year in 2022 to 65,46 kWh/m²/year, mainly due to the low level of loan disbursements despite continued generous grants. In 2024, EE rebounded modestly. While the RE share was high at 29.44% in 2022, it reduced in 2023 and then stabilized in 2024. Stable household income in 2024, deteriorating energy prices, and sidelined awareness potentially muted the momentum to invest in RE. However, consistent incentives of policy stimulated the gradual expansion of the green projects.

Germany had a stable upward trajectory - EE increased from 77,43 kWh/m²/year in 2022 to 90,75 kWh/m²/year in 2024. This development is congruent with increased income levels, consistent access to loans, and increased public awareness. The level of RE increased from 32.72% to 39.84%, which shows the effort of the government to introduce financial support and awareness campaigns at the national level. Feed-in tariffs remained within an optimistic spectrum of 0.17-0.19 USD/kWh, and policy support continued to be strong, which prompted the public to invest in the installation of renewable energy.

There was massive growth in EE in China from 67,69 in 2022 to 91,91 in 2024, and this was accompanied by a sizeable increase in RE share, from 22,73% to 51,46%. Such positive changes are associated with a significant increase in available loans, increased subsidies, as well as increased public awareness alongside the feed-in tariff rates. Government support was always strong, which implied a unified policy effort that merged fiscal inducements and public encouragement. This

improvement indicates China's excellent record in changing household-level energy systems.

Although it started from a less advanced initial level, Ukraine also enjoyed considerable progress. EE increased from 65,43 in 2022 to 85,49 in 2024, and penetration of RE increased from 12,66% to 28,41% in the same period. Nevertheless, those improvements took place despite moderate rates of income and uneven availability of loans. However, Ukraine won further support as a result of increased subsidies, improved policy measures, and willful efforts to promote awareness and re-adjust tariffs. The persistent growth in EE and RE demonstrates that, despite economic difficulties, money has been expended in proper manners.

Analysis reveals that countries such as China and Germany, which successfully blend high rates of subsidy, availability of green loans, facilitated by strong policy and informed public in national development, enjoy rapid and steady progression in terms of EE and RE. In comparison, countries with varying aspects of these factors (including the UK and Ukraine) record less stable outcomes. In spite of its high income levels and strong tariffs, the USA demonstrated inconsistency, which may be triggered by variation in the availability of a loan/shifts in policy.

Table 1 demonstrates the critical interplay of one set of financial incentives, the social and economic factors and the policy measures in promoting household-level energy transitions. Countries that coordinate these strategies, namely through feed-in tariffs, specific subsidies, and public campaigns, experience the highest levels of improvement in energy savings and RE consumption. The results point to the need for concerted national efforts where the fiscal policies are also congruent with individual as well as institutional practices that would help combat sustainability in energy use (Table 2).

Table 2

Impact of financial and policy variables on household EE and RE adoption (econometric model results)

Variable	Coefficient_ EE	Std_Error_ EE	P_Value_ EE	Coefficient_ RE	Std_Error_ RE	P_Value_ RE
Subsidies	0,021	0,009	0,018	0,017	0,007	0,012
Loans	0,034	0,011	0,005	0,028	0,01	0,008
Income	0,0012	0,0005	0,032	0,0021	0,0006	0,027
EnergyPrices	-0,056	0,014	0,001	-0,042	0,015	0,005
Awareness	0,087	0,023	0			
GovSupport	0,043	0,018	0,013	0,038	0,014	0,011
FeedInTariff	-	-	-	0,069	0,02	0,002

Source: author's development based on the results of an econometric model using data [11-20].

The findings show that support for such development is achieved efficiently through funding tools such as subsidies and green financing alternatives and policy frameworks. These conclusions are based on, and extend from earlier studies on links between finance, innovation, and sustainability (Xie et al., 2022; Majewska & Bełtowska, 2023; Prokopenko et al., 2023; Tvaronavicienė, 2024). Current research emphasizes other aspects of this relationship, validating the importance of the cross-country modeling framework of this study, while also suggesting the potential for additional research in this field.

Mugunzva and Manchidi emphasize the importance of integrating artificial intelligence into entrepreneurship, the tool that may be powerful enough to change strategic decision-making processes [21]. Though research does not focus on household energy transitions, their discussion of AI fuse dynamic, data-informed frameworks complements the insights from the current study. We agree that the application of improved modeling and predictive algorithms might enhance the development and implementation of financial instruments of household EE, where one could have the flexibility of distributing the subsidies or individual incentives based on energy usage. This alignment is justified as the integration of AI-based

modeling allows for a more precise allocation of financial incentives, which our econometric results confirm is critical for improving energy efficiency outcomes, especially in Ukraine, where targeted subsidies and adaptive financing have shown stronger impact in regions with higher public awareness and stable political support.

Majewska and Bełtowska study socially responsible investing through the eyes of younger consumers, which reflects the bond between sustainability and financial results [22]. Through emphasizing this dynamic, the study clarifies how social shifts specify the efficiency of financial tools. Our findings support this view: a 1% increase in public awareness (awareness index) leads to a 0.87% increase in household energy efficiency, as demonstrated by the coefficient of 0.087 in our EE model. Similarly, a 1% increase in subsidies correlates with a 0.021% rise in EE and a 0.017% rise in RE, while green loans have an even stronger effect, with a 1% increase contributing to a 0.034% rise in EE and 0.028% in RE. These results empirically confirm the importance of combining financial stimuli with informational and policy measures, especially in contexts like Ukraine where awareness campaigns and institutional trust are still being formed. Majewska and Bełtowska's study is relevant because it highlights the relationship between public trust, awareness, and the effectiveness of sustainable development financial instruments. Our modeling results confirm that in countries with higher levels of public awareness and stable political support, financial incentives produce better results. This is especially true for Ukraine, where increased trust in government programs and enhanced information campaigns can significantly increase household participation in green financing programs.

As we have focused on household energy data, Chovancová et al.'s study performed a decomposition analysis of energy consumption and GHG emissions among EU countries [23]. The study reveals significant variances as far as patterns of energy use are concerned and highlights the need for customized approaches. This fits with our study's use of cross-country differentiation, meaning that the financial

tools presented should be adapted to cater for regional conditions, with the contradictory movements in countries like China, Ukraine and UK serving as an example.

Pariso, Picariello, and Marino address the challenge of accessing scarce raw materials in a circular economy [24]. Even though, predominantly paying attention towards industrial sectors, the material shortages also are applicable to the residential energy systems, especially from the perspective of installing photovoltaic systems or the advanced smart energy technologies. This concurs with Tvaronavicienė's argument that a transition to RE implies sustainable resource management [25]. Our research advances the state of knowledge by demonstrating that financial mechanisms can spur the adoption of these technologies among households when material supply is optimal.

For business and investment, Prokopenko et al. study the manner in which investment into renewable technology R&D affects corporate profitability [26]. Their discovery indicates that participating in financial terms of green innovation is associated with better corporate performance. This, in real terms means that, households may benefit from the sustainable investment in energy-efficient technology – as long as the financial terms are right, which this study supports.

Prokopenko et al. examine the impact of the blockchain on financial accounting and transparency [27]. Although not directly related to energy, there is potential for blockchain technology in facilitating energy transitions within households by its use to manage subsidy programs, their tracking, or in developing decentralized green bonds. This technological approach is aligned with the views of Koldovskiy [28], who promotes the transformation of strategic infrastructure to reinforce the financial sector's effectiveness. In our study, infrastructure transformation, especially digitalization, can facilitate the allocation of green financing to households, which in turn improves accountability and responsiveness.

All these studies validate our research's underlying hypothesis. Most of the studies cited do not focus directly on financial mechanisms, but they do highlight the importance of the relationship between political support, awareness, and institutional stability in achieving sustainable outcomes. These factors are key variables in our econometric model that determine the effectiveness of financial instruments for households. Thus, previous studies provide context and support for our hypothesis that socio-economic factors have a complex impact on the effectiveness of financial support. Financial mechanisms are of great importance in facilitating the energy transition, but they need to be placed in the context of a broader socio-technical and economic frame. Our research is consistent with current academic views and adds to the knowledge on the topic through customizing data from various countries and in-depth modelling. The contradictions in country-specific results are consistent with the scholarly discourse on institutional capabilities, policy consistency, and regional disparities, highlighting the inadequacies of a one-size-fits-all approach.

This research in general contributes to academic discussion as it empirically illustrates how households respond to the financial factors in terms of the use of energy, confirms prior findings, and provides novel associations between financial strategies, social features, and digital development. Using behavioural insights and digital harnessing capabilities can offer promising avenues to enhance both equity and effectiveness of future energy policies.

Based on the Ukrainian data, it is advisable to individualize financial incentives with reference to local socio-economic predicament and make subsidy allocation more transparent. Implementation of more digital monitoring systems and a roll-out of targeted awareness ventures can have a significant effect on the level of household participation in sustainable energy programs. Focusing on steady policy and providing more support to poor households in regions with low energy use could tackle this issue in Germany. If China puts in place digital transparency and educates

its communities, it can better line up its financial distribution with the resulting behaviors. Ensuring credit is available and borrowers are content about procedures in the UK and USA might improve the use of existing green financing programs.

Conclusions. This inquiry examined the influence of financial measures such as subsidies, loans, income, pricing structures and policy incentives on improving household energy efficiency and penetration of renewable energy solutions. It was established that a combination of public subsidies, targeted loan programs, and encouraging governmental policies notably increases household EE as well as the adoption of renewable energy. In addition, the study revealed that public awareness enhancement and continuous feed-in tariffs substantially intensify the effects of these financial instruments especially when they are implemented under stable institutional frameworks.

The main goal of the research was to measure and simulate how financial and policy factors are affecting household energy practices and confirm the achievement of the goal from the findings. High-performing countries were able to effectively merge fiscal tools with greater systemic and behavioral efforts. Performance gap implies that national strategies should be tailored to the smooth-running of the local environment and budgeted economy in promoting efficient energy behavior.

While, the research gives valuable insights about the significance of financial incentives, it nonetheless also indicates certain deficiencies that require further investigation. Research henceforth should address sustained elements of behavior change driven by financial incentives, explore the impact of digital development on EE, and test the possibility of decentralized financing options like green bonds, and peer-to-peer energy finance. By looking at a more comprehensive set of data from other countries during a longer period of time, researchers will be able to identify the contextual structural factors that are shaping household-level energy shifts.

The publication was prepared in the framework of the research project "Formation of economic mechanisms to increase energy efficiency and provide sustainable development of renewable energy in Ukraine's households" (No. 0122U001233), funded by the National Research Foundation of Ukraine.

References

1. Xie, Q. C., Bai, D. C., & Cong, X. P. (2022). Modeling the dynamic influences of economic growth and financial development on energy consumption in emerging economies: Insights from dynamic nonlinear approaches. Energy Economics, 116, 12. https://doi.org/10.1016/j.eneco.2022.106404

2. Yu, X. L., Zhou, Y., & Liu, X. J. (2022). Impact of financial development on energy consumption in China: A spatial spillover analysis. Energy Strategy Reviews, 44, 12. https://doi.org/10.1016/j.esr.2022.100975

3. Petrović, S., Colangelo, A., Balyk, O., Delmastro, C., Gargiulo, M., Simonsen, M. B., & Karlsson, K. (2020). The role of data centres in the future Danish energy system. Energy, 194, 116928. https://doi.org/10.1016/j.energy.2020.116928

4. Algarni, S., Tirth, V., Alqahtani, T., Alshehery, S., & Kshirsagar, P. (2023). Contribution of renewable energy sources to the environmental impacts and economic benefits for sustainable development. Sustainable Energy Technologies and Assessments, 56, 103098. https://doi.org/ 10.1016/j.seta.2023.103098

5. Farghali, M., Osman, A. I., Chen, Z., Abdelhaleem, A., Ihara, I., Mohamed, I. M. A., Yap, P. S., & Rooney, D. W. (2023). Social, environmental, and economic consequences of integrating renewable energies in the electricity sector: A review. Environmental Chemistry Letters, 21, 1381–1418. https://doi.org/10.1007/s10311-023-01587-1

6. Orlando, M., Bottaccioli, L., Quer, S., Poncino, M., Vinco, S., & Patti, E. (2023). A framework for economic and environmental benefit through renewable

energy community. IEEE Systems Journal, 17, 5626–5635. https://doi.org/10.1109/JSYST.2023.3290941

7. Adanma, U. M., & Ogunbiyi, E. O. (2024). Assessing the economic and environmental impacts of renewable energy adoption across different global regions. Engineering Science and Technology Journal, 5, 1767–1793. https://doi.org/10.51594/estj.v5i5.1154

8. Łęgowik-Małolepsza, M., Kollmann, J., & Chamrada, D. (2024). Eco-marketing and the competitive strategy of enterprises - Review of the research results of energy companies. Entrepreneurship and Sustainability Issues, 11, 135–153. http://doi.org/10.9770/jesi.2024.11.3(9)

9. Antonioli, D., Chioatto, E., & Mazzanti, M. (2022). Innovations and the circular economy: A national and regional perspective. Insights into Regional Development, 4, 57–70. https://doi.org/ 10.9770/ird.2022.4.1(4)

10. Yalçınkaya, A., Feyzioglu, A., Boyraz, C., Haliloglu, H., Santoro, D., & Piccinetti, L. (2024). Demand side response program for more sustainable electricity market: A case study of Türkiye. Insights into Regional Development, 6, 11–22. https://doi.org/10.9770/IRD.2024.6.1(1)

11. International Energy Agency. (2024). Energy efficiency indicators 2024: Data and statistics. https://www.iea.org/statistics

12. World Bank. (2023). World development indicators: Energy use, subsidies, and household income. https://databank.worldbank.org/source/world-development-indicators

13. International Renewable Energy Agency. (2024). Renewable energy statistics 2024. https://www.irena.org/Statistics

14. OECD. (2024). Household energy pricing, subsidies, and fiscal support database. https://www.oecd.org/energy/

15. International Monetary Fund. (2023). Global energy subsidies: Estimates and fiscal trends. https://www.imf.org/en/Data

16. United Nations Economic Commission for Europe. (2024). Sustainable energy tracking in residential sectors. https://unece.org/energy

17. European Environment Agency. (2023). Support schemes and environmental awareness indicators in EU households. https://www.eea.europa.eu/

18. National Renewable Energy Laboratory. (2024). Policy mechanisms for residential renewable energy: Feed-in tariffs and beyond. https://www.nrel.gov/international/

19. United Nations Development Programme. (2024). Advancing household sustainability: Energy access and financing trends. https://www.undp.org/publications

20. Statista. (2023). Public awareness, energy pricing, and green financing statistics by country. https://www.statista.com

21. Mugunzva, F. I., & Manchidi, N. H. (2024). Re-envisioning the artificial intelligence-entrepreneurship nexus: A pioneering synthesis and future pathways. Insights into Regional Development, 6, 71–84. https://doi.org/ 10.70132/k5546584395

22. Majewska, A., & Bełtowska, P. (2023). Socially responsible investing (SRI) as a factor of competitiveness and sustainable development of organisations in young consumers' opinion. Entrepreneurship and Sustainability Issues, 10, 245–262. https://doi.org/10.9770/jesi.2023.10.4(15)

23. Chovancová, J., Štofejová, L., Gavura, S., Novotný, R., & Rigelský, M. (2024). Assessing energy consumption and greenhouse gas emissions in EU member states - Decomposition analysis. Entrepreneurship and Sustainability Issues, 11, 242–259. https://doi.org/ 10.9770/jesi.2024.11.4(15)

24. Pariso, P., Picariello, M., & Marino, A. (2023). Circular economy and rare materials: A challenge for the European countries. Entrepreneurship and Sustainability Issues, 11, 79–92. https://doi.org/ 10.9770/jesi.2023.11.2(6)

25. Tvaronavicienė, M. (2024). The transition towards renewable energy: The challenge of sustainable resource management for a circular economy. Energies, 17, 4242. https://doi.org/10.3390/en17174242

26. Prokopenko, O., Kurbatova, T., Khalilova, M., Zerkal, A., Prause, G., Binda, J., Berdiyorov, T., Klapkiv, Y., Sanetra-Półgrabi, S., & Komarnitskyi, I. (2023). Impact of investments and R&D costs in renewable energy technologies on companies' profitability indicators: Assessment and forecast. Energies, 16(3), 1021. https://doi.org/10.3390/en16031021

27. Prokopenko, O., Koldovskiy, A., Khalilova, M., Orazbayeva, A., & Machado, J. (2024). Development of Blockchain Technology in Financial Accounting. Computation, 12(12), 250. https://doi.org/10.3390/computation12120250

28. Koldovskiy, A. (2024). Strategic infrastructure transformation: Revolutionizing financial sector management for enhanced success. Acta Academiae Beregsasiensis. Economics, 5(2024), 323–332. https://doi.org/10.58423/2786-6742/2024-5-323-332

29. Kostyrko, R., Kosova, T., Kostyrko, L., Zaitseva, L., & Melnychenko, O. (2021). Ukrainian Market of Electrical Energy: Reforming, Financing, Innovative Investment, Efficiency Analysis, and Audit. Energies, 14(16), 5080. https://doi.org/10.3390/en14165080

30. Kuzior, A., Lobanova, A., & Kalashnikova, L. (2021). Green Energy in Ukraine: State, Public Demands, and Trends. Energies, 14(22), 7745. https://doi.org/10.3390/en14227745

31. Sabishchenko, O., Rębilas, R., Sczygiol, N., & Urbański, M. (2020). Ukraine Energy Sector Management Using Hybrid Renewable Energy Systems. Energies, 13(7), 1776. https://doi.org/10.3390/en13071776

32. United Nations Framework Convention on Climate Change. (2015). The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

33. European Commission. (2019). The European Green Deal (COM(2019) 640 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640

34. Cabinet of Ministers of Ukraine. (2023). National Energy and Climate Plan of Ukraine until 2030. https://www.mepr.gov.ua/news/40049.html