



RESEARCH ARTICLE

REVISED Design choices of energy interface for rural area**consumers in Finland**

[version 2; peer review: 1 approved, 1 approved with reservations]

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Abstract**Background**

This paper reports on the measures taken to develop a structured and organized approach to understanding the various design elements used in the energy interface. The approach taken in this study involves a decision-making process that selects energy interface elements from both the consumer's and developer's perspectives.

Methods

The decision-making process utilized the Analytic Hierarchy Process (AHP) methodology, which integrates mathematical and psychological principles. A panel of experts was invited to take part in the workshop activity to choose the best option by quantifying subjective judgments and synthesizing the opinions into a clear result using the AHP framework.

Results

The evaluation rounds with participants revealed key insights into points such as affordability and usability, which were crucial in energy consumers' priorities. Also, consumers prefer advanced technology features, particularly in mobile devices and smart home integration.

Conclusions

The recommendations from the decision-making process, which include stressing the distinct needs of various energy consumer groups, can help future product development and marketing strategies.

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Plain language summary

This study looked at how to make better decisions when designing energy app interfaces for rural energy consumers living in rural areas of Finland (like apps or devices people use to manage their energy). The study used a method called the Analytic Hierarchy Process (AHP), which helps turn people's opinions and preferences into clear, measurable results. A group of experts took part in workshops to decide which design features were most important from both the consumer's and developer's points of view. The findings showed that affordability and ease of use matter most to consumers. People also like advanced technology features, especially ones that work with smart home systems. The study suggests that the energy interface should be designed and marketed with the specific needs, for example, the home-heating needs of consumers living in rural areas.

Keywords

Energy behavior, energy consumer, user interface, energy interface, design choices, ahp analysis



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REVISED Amendments from Version 1

In response to the insightful feedback provided in the reviews, I have implemented several key changes to enhance the professionalism, readability, and depth of the article. These revisions aim to elevate the scientific rigor of the content, ensuring that it meets the high standards expected in academic discourse.

Any further responses from the reviewers can be found at the end of the article

Introduction

For energy consumers living in cold climates, such as rural areas of Finland, energy costs are not just another utility bill; they are a fundamental aspect of life that cannot be overlooked as energy consumption for heating is essential during the winter season in harsh environments, also it is necessary to maintain the quality of homes, water piping, and infrastructure (Sandberg *et al.*, 2018). The cost of energy significantly influences the standard of living, especially during the winter months. For energy consumers, various factors influence their energy usage behavior, with energy data visualization being one such aspect (Qureshi *et al.*, 2025). Energy data visualization is displaying energy statistics through a user interface, which is often more important to energy consumers in colder climates than in milder ones. This is mainly due to changing weather conditions and complex dynamic factors, such as heating needs and available energy contracts.

Previous studies conducted within the same demographic in Finnish rural area have identified four groups of energy consumers based on energy consumption and monitoring behaviors categorize from A to D where group A are consumers who less concerned about energy monitoring and consume as much energy as they need. As we move down the scale to Group D, consumers become increasingly focused on energy monitoring and saving. Group D members actively seek to maximize their energy savings, often adjusting their consumption routines based on energy prices (Qureshi *et al.*, 2024). The consumer groups highlighted by the study can be summed into two categories, where the first category consists of tech-savvy individuals who seek advanced features and new energy solutions. The second category includes more traditional, non-affluent consumers who focus on saving energy by modifying their energy consumption habits.

This study is about the energy interface design elements, which provide access to different energy statistics, allowing consumers to monitor and manage their energy consumption. While there are technologies available for providing energy data statistics, most of these are designed as “one size fits all” solutions aimed at automating energy data visualization for the general public. However, such solutions frequently fail to take into account the diverse cultural and social practices of local communities (Berkovsky *et al.*, 2015; Irizar-Arrieta *et al.*, 2018; Wickramathilaka *et al.*, 2025). This oversight can result in inefficient or, in some cases, inappropriate systems that do not adequately meet local needs.

The early interviews and workshop studies were primarily focused on understanding energy consumer practices and their visualization priorities, especially during periods of price hikes. Previous studies have also identified various design elements of energy interface that are relevant to rural energy consumers based on their practices. This paper builds on these findings by employing a user-centered approach that involves experts and engineers to address the challenge of identifying suitable interface design elements for different types of energy users. The experts will evaluate various design elements of the energy user interface from two distinct perspectives, which correspond to the two groups of consumers identified through end-user interviews in existing literature.

The research first question (RQ1) analyzes design principles from the consumer’s perspective. The second research question (RQ2) addresses the developer’s perspective. Together, these questions aim to understand the relationship between user requirements and developer insights in the design of energy interfaces.

RQ1: What design principles and software features are most suitable for different demographic groups based on their unique needs?

RQ2: What design elements do software developers and engineers find most appropriate for energy interfaces?

While previous research has utilized the AHP framework for user interface design, this study provides a novel technical contribution by specifically applying AHP to reconcile the differing priorities of rural energy consumers in cold climates with those of software engineers. Unlike generic AHP interface evaluations, this research synthesizes prior qualitative behavioral data with expert pairwise comparisons to generate highly specific, context-aware design choices for two distinct consumer profiles (tech-savvy and non-affluent).

The paper is structured into several sections. The literature review explores energy interfaces and data visualization from the available perspectives. Following this, the paper highlights the importance of decision-making for energy consumers, focusing on user-centered design and co-design activities, such as the primary method used for decision making, the Analytic Hierarchy Process (AHP) analysis. The sections on research setup and findings provide a detailed account of the progress and results of the study methods. Finally, the discussion and conclusion summarize the outcomes of the study.

Literature review

Energy interface is a user interface designed specifically for energy consumers, showing the visualization of energy data. User interface success relies on engaging users and being user-centric (Irizar-Arrieta & Casado-Mansilla, 2017), as it highlights the necessity for prioritizing specific user needs and preferences, which is hard to achieve without a user-centered design approach (Fortmann & Glanert, 2019). This involves gathering feedback from potential users to ensure the interface aligns with their expectations. Additionally, continuous prototype testing plays a crucial role in enhancing the user experience (Escanillan-Galera & Vilela-Malabanan, 2019). By iterating on design based on user feedback, developers can refine the interface, address usability issues, and ultimately empower consumers with better control over their energy data visualization.

Energy consumers living in Finnish urban and Finnish rural areas have specific differences in their energy usage. As a country with a cold climate, the rural consumers often use energy differently than their urban counterparts due to variations in housing types, available heating infrastructure, and lifestyle choices (Juntunen & Asikainen, 2023). For instance, rural residents frequently rely on oil and wood for space and water heating. In contrast, urban consumers typically have access to centralized heating systems provided by municipalities and hot water, which are often more affordable or, in some cases, may be included in the monthly rent (Finnish district heating year 2006, 2007). The rural households lack centralized heating; they tend to be more self-reliant for their water and space heating needs. This independence often leads them to invest in alternative energy sources, such as solar power with battery storage, as they have the available space around their houses and also more motivation to pursue these options than people living in limited living spaces.

As early research has shown that the energy consumption behavior is clearly reflected in energy data visualization (Qureshi *et al.*, 2025). Consumers with access to city heating are less inclined to search for cheaper energy contracts or to monitor when energy prices are low. For those living in urban areas, the lack of incentive to invest time in searching for savings often results in minimal financial benefit. In contrast, consumers in rural areas are more motivated, as even small savings can accumulate to a significant amount over time. In our interview study, participants explained how even a few cents lower in energy costs can lead to substantial savings by the end of the winter season.

Prior studies on energy interfaces have primarily focused on standardizing design for general populations, often relying on end-user Interviews, and surveys. For example, highlighting user diversity in rural Finnish environments, those previous studies do not fully address the unique infrastructural constraints of rural environments. Previous research focuses on the usability of mobile energy apps but lacks a rigorous, mathematically weighted evaluation of conflicting design priorities. This study fills this gap by employing AHP to formally quantify and compare these distinct design elements from an expert panel's perspective, moving beyond qualitative surveys to structured decision-making.

One of the structured methods used to organize and analyze complex decisions is the AHP, or the Analytic Hierarchy Process, developed by Thomas L. Saaty in the 1970s, this technique combines principles from mathematics and psychology (Improta *et al.*, 2019; Ramík, 2020; Xiulin & Dawei, 2014). It is a multi-criteria decision-making tool that simplifies complex decisions by breaking them down into smaller, more manageable parts and then applying different comparisons before synthesizing the results based on ranks and priorities (Gasparotti & Domnisoru, 2020; Nonaka *et al.*, 2008). The comparison can be, for example, for selecting something, evaluating, cost-benefit analysis, priority and ranking and decision making in general; the method can also be used as sole tool or it can be combined with other methods, such as fuzzy set theory or statistics (Akram & Adeel, 2023).

The user interface for energy data visualization serves as a crucial medium between energy consumers and providers. It relies on a visual design grounded in human factors engineering to enhance interface design (de Souza Santos & de Almeida Neris, 2015), prioritizing clarity and convenience while also aligning with local culture and human emotions. This approach aims to make user interactions as easy and natural as possible by considering users' needs and preferences throughout the design process (Kheder, 2023; Xu, 2023).

Research method and setup

The process and steps taken to our methodology are illustrated in Figure 1 below.

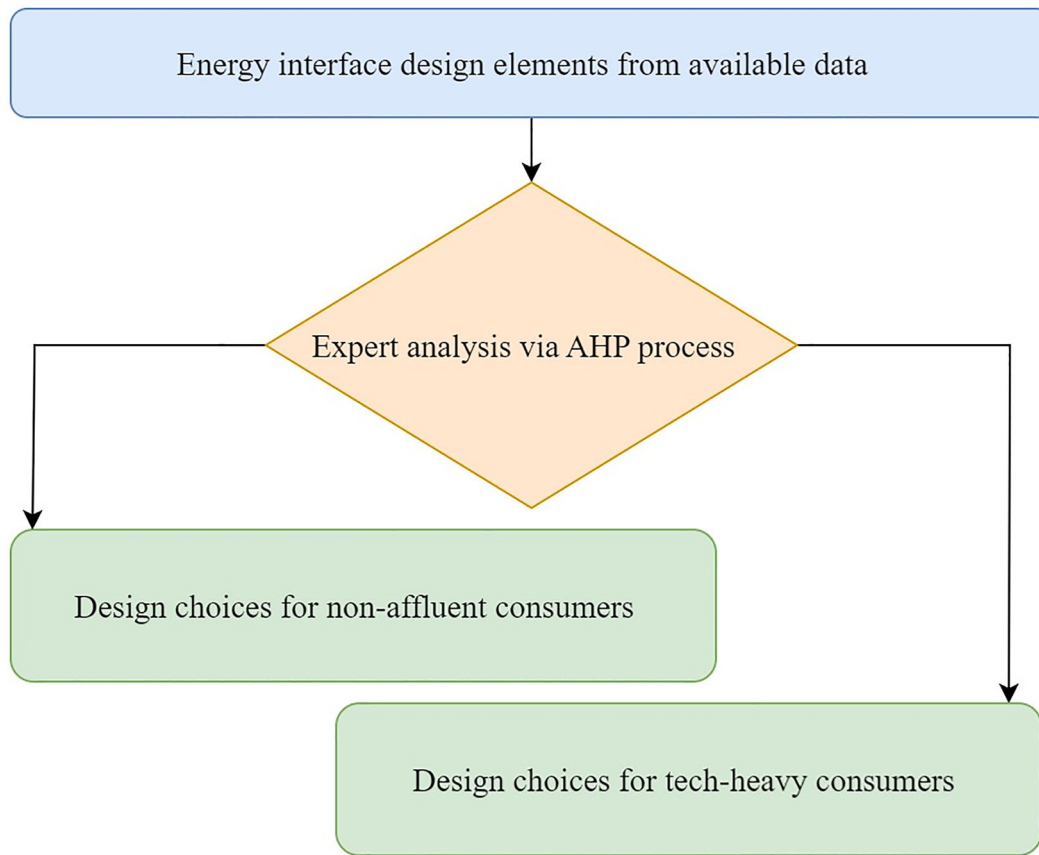


Figure 1. Three steps of the study in different colors.

Research method

Previous studies and literature reviews have examined energy data visualization behaviors among consumers in rural areas, highlighting their priorities regarding energy usage and price monitoring (Qureshi *et al.*, 2024). They have also focused on various types of energy consumption, such as heating and household usage. While considerable data has been collected from previous research, showing the design requirements of energy consumers. A significant aspect of research was lacking, which is the expert's perspective on interface design elements and feedback on the integration of different elements into energy interface, such as engagement, usability, and functionality from software engineering perspective.

The criteria used to build the AHP hierarchy were extracted from foundational datasets gathered in previous peer-reviewed studies targeting the exact demographic of this research. The validity and consistency of these datasets were ensured through rigorous qualitative methodologies, including thematic analysis of semi-structured interviews with rural energy consumers. Because this prior data successfully saturated the core behavioral themes, for example, identifying the energy profiles of consumers, including the 'tech-savvy' and 'non-affluent' consumers. These studies provide a grounded basis for establishing the AHP evaluation criteria in this study.

In this study we used the decision-making process to evaluate these findings by including insights from experts, software developers, electrical engineers, and energy consumers. Central step in our methodology is the analysis process using the Analytic Hierarchy Process (AHP) framework which is a structured decision-making method that helps break down complex problems into a hierarchy of goals for conducting pairwise comparison (Ramík, 2020). This approach simplifies decision-making by converting subjective judgments into a structured format and using mathematical calculations. The outcome is a consensus-based, prioritized solution (Xiulin & Dawei, 2014).

Research has shown that the Analytic Hierarchy Process (AHP) is an effective tool for selecting design options in user interface design (Arango *et al.*, 2025; Yamada *et al.*, 2009). The AHP framework has been used to facilitate group decision-making, recognizing the value of collective wisdom for improved outcomes (Lee & Jalao, 2017). Compared to other frameworks, AHP has been evaluated alongside Data Envelopment Analysis (DEA) in the context of benefit-cost

analysis, highlighting the potential trade-offs between the two methods (Tone, 2016). It enables decision-makers to quantify both subjective human judgments and objective evaluations (2023). This makes it a widely accepted and reliable method for calculating the weights of attributes in the decision-making environment. In our case, it facilitates the participation of energy consumers and software designers, empowering them to make informed and effective decisions.

There are various AHP tools available across multiple platforms, including web-based AHP systems such as AHP-OS which also used in this study, (Goepel, 2018). These tools offer detailed analyses, support group input, facilitate consensus calculations, and enable sensitivity analysis. This enhances the accessibility and usability of AHP, making it valuable for research purposes. To ensure methodological transparency and avoid a ‘black box’ reliance on the AHP-OS software, a manual verification step was introduced. A sample of the pairwise comparison matrices (specifically the Level 1 primary criteria) was exported and the principal and consistency ratios were manually recalculated using standard spreadsheet software. This cross-validation confirmed that the software’s algorithmic outputs perfectly aligned with traditional AHP mathematical derivations.

In this study we structured the problem as a hierarchy, as per the AHP analysis framework requirements, using the design elements of the energy interface that were identified in data from previous studies. The criteria and sub-criteria populating the AHP hierarchy were not arbitrarily chosen; they were derived through a rigorous thematic extraction process based on existing empirical data (Qureshi et al., 2024, 2025). The most frequently cited interface elements, consumer discomfort points, and behavioral preferences identified in the qualitative transcripts of rural energy consumers were categorized. These themes were then systematically mapped to the Level 1 (e.g., Interactivity, Features) and Level 2 (e.g., Gamification, Smart Devices) criteria to ensure the AHP model was entirely grounded in validated end-user requirements.

The hierarchical table divides design elements into different categories and sub-categories, serving as the basis for subsequent analysis by the AHP framework (see Table 1 below). At the top level, designated as Level 0, contains the main categories listed as “Interactivity, Interface, Features, Limitations, and Demographics.” Level 1 consists of the sub-criteria, which are divided into multiple sub-categories. At Level 3, each variable from Level 2 has been further broken down into sub-criteria. For instance, the Usability criterion includes sub-criteria such as “clear prompts” and “error prevention.” Similarly, the other Level 2 criteria also have their respective sub-criteria, as shown in Table 1 below.

The hierarchical structure of the AHP model was directly developed to address the study’s research questions. To answer RQ1 (consumer demographic needs), the hierarchy includes criteria such as ‘Interactivity,’ ‘Interfaces,’ and ‘Features,’ which capture the end-user’s desired functionalities and engagement preferences. To address RQ2 (developer perspectives), the ‘Limitations’ and ‘Demographics’ nodes were integrated to account for structural feasibility, such as development costs and integration difficulties. Table 1 outlines how these dual perspectives were synthesized into a single, cohesive decision model.

Table 1. Design elements of energy user interface.

MAIN LEVEL	SUB LEVEL 1	SUB LEVEL 2
INTERACTIVITY	Gamefulness	Gamification Serious games
	Game play	Notifications Challenges Game storyline
	Smart devices	IoT Smart meter
	Passive	Leaderboards Intrinsic motivation Extrinsic motivation Progress sharing Rewards
INTERFACES	Smart devices	TV Mobile Evs
	Web	Internet Apps/Applications
	Broadcast	Tv Radio
FEATURES	Customizations	Consumer data Billing information Energy consumption
	Energy statistics	Live energy data Solar energy production Feedback on Energy Current bill
LIMITATIONS	Cost	App development Continue development
	Complexity	Meeting consumer demands Integrating devices
DEMOGRAPHICS	Human behavior	Changing human behavior Different energy contracts
	Culture differences	Different energy profiles Prioritizing some energy usage

The above-mentioned table served as the basis for subsequent analysis, fourteen (14) experts were invited to participate in the decision-making process. Each participant contributed their opinions through pairwise comparisons and assigned a weight on a scale from 1 to 9 for each pair, reflecting their views. Verbally informed consent and data processing permission were obtained, since all members of the expert panel were employees of LUT University at the time of writing the paper it was not required to have ethical approval, the Extended data contains confirmation from the LUT Ethics Committee (see extended data, confirmation from the LUT Ethics).

No manual matrix calculation was carried out, only the web based AHP analysis framework, AHP-OS (Goepel, 2018) was used to calculate steps in the process. This process resulted in a global priority score for each alternative, combining statistical data with personal preferences to yield a clear, mathematically derived answer.

Mathematical Formulation of the AHP Model

While the AHP-OS software was utilized for computation, the underlying hierarchical decision model relies on standard AHP mathematical principles. The expert judgments are structured into a pairwise comparison matrix A of size $n \times n$:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}$$

where a_{ij} represents the relative importance of criteria i over criteria j , and adheres to the reciprocal rule $a_{ji} = 1/a_{ij}$.

To derive the global priorities (weights), the principal eigenvector w is calculated by solving the eigenvalue problem:

$$A * w = \lambda_{\max} * w$$

where $\lambda_{\max}$ is the maximum eigenvalue of matrix A . Finally, to ensure the reliability of the expert judgments, the Consistency Index (CI) and Consistency Ratio (CR) are computed:

$$CI = \frac{(\lambda_{\max} - n)}{(n - 1)}$$

$$CR = \frac{CI}{RI}$$

where RI is the Random Index value dependent on the matrix size n . This mathematical structure ensures that the qualitative expert opinions are rigorously translated into quantitative weights.

Because this study involved a panel of fourteen experts, it was necessary to synthesize their individual evaluations into a single consensus model. The aggregation of multiple expert judgments was conducted using the Aggregation of Individual Judgments (AIJ) approach. Specifically, the AHP-OS software calculated the geometric mean of the individual pairwise comparisons to form a single, aggregated consensus matrix for each consumer profile. The geometric mean is the mathematically appropriate method for AHP group decision-making, as it preserves the reciprocal properties of the comparison matrices and prevents extreme outlier judgments from skewing the final priorities.

Once the local priorities are established for each sub-criterion, the global priorities are computed to determine the overall weight of each design element in relation to the primary goal. This is achieved by multiplying the local weight of the sub-criterion by the global weight of its parent criterion in the hierarchy. This hierarchical weighting ensures that the final percentage scores accurately reflect both the micro-level comparisons and the macro-level category importance.

Research setup

The workshop was organized with the primary objectives of facilitating problem-solving, encouraging brainstorming, and facilitating decision-making activities. Within this framework, the workshop featured a singular yet significant Analytic Hierarchy Process (AHP) activity, during which participants engaged in pairwise comparisons to evaluate various criteria. Before the workshop activity, fourteen experts, including both in-person and those joining online, were selected through convenience sampling. This panel of experts received an introduction to the AHP web-based software, and how to navigate the system and effectively provide their evaluations, also the link for login was provided for each participant. The panel consists of the following experts, and this diverse group brought a range of expertise to the workshop activity.

- A professor of software engineering specializing in community software.
- A software engineering professional with a Master of Science (M.Sc.) degree.
- Two researchers focused on energy networks and markets.
- A researcher studying energy interactions.
- A software engineering researcher with an emphasis on ethics in games.

While a sample size of fourteen participants might be considered small for traditional statistical generalization, it is highly appropriate and robust for Multi-Criteria Decision Making (MCDM) frameworks such as AHP. Unlike large-scale population surveys, AHP relies on the deep, qualitative insights of qualified domain experts. Existing literature on AHP methodology establishes that expert panels typically ranging from 5 to 15 individuals are sufficient to achieve a reliable consensus, as the focus is on the consistency and quality of the pairwise comparisons rather than statistical volume.

Each participant contributed their opinions through pairwise comparisons and assigned a weight on a scale from 1 to 9 for each pair, reflecting their views. The essence of the AHP is the comparison. If we have a simple case of three options A, B and C, the experts compare each option against each other. A to B, A to C and B to C. If they are on the same level the value is 1 for both. If one option is more important in some way it gets a higher value. Usually 3, 5, 7 or 9, but also even numbers can be used if the jump, for example, from 3 to 5 is considered too high. 9 means absolute importance. One side gets a value between 1 and 9 and the opposite side gets then the inverted value, for example 1/5, based on the comparisons. If the weights for different options are not equal, the eigenvectors can be multiplied by the weights of the criteria. In the end there is 1xN eigenvector giving the final values for the comparison. As the sum of values in eigenvector is 1, the numbers can be easily transformed into percentage values. With a consistency ratio and consistency index it is also possible to check whether the judgment is valid (ALONSO & LAMATA, 2006).

While the session was initially scheduled to last one hour, the engaging discussions and the feedback resulted in the activity extending to approximately one and a half hours. Participants took the time to spend on their analyses, ensuring a thorough comparison. At the conclusion of the workshop, the results of the AHP activity were presented to all participants, providing an opportunity for reflection. This closing segment aimed to consolidate the insights gained and enhance collective understanding among the group. The data available in the online repository can be imported to recreate the project and can also be used for analyzing the results (Qureshi, 2025). The data has been anonymized, with participants' names replaced by identifiers ranging from PPA to PPQ, where "PP" stands for project participants.

Findings

Current study is about the energy data visualization preferences of rural residents in the East Karelia region of Finland. The study used data collected from previous studies in the same geographical area. This existing data offers various viewpoints from energy consumers, gathered through multiple methods, and identifies two main types of consumers. We synthesized early findings by aggregating the opinions of experts and consumers within a hierarchical structure and utilizing the Analytic Hierarchy Process (AHP) framework. Previous studies also highlighted different design elements of energy interfaces and identified two consumer categories: "non-affluent consumers" and "non-tech-savvy, highly impacted" energy consumers. AHP analyzed both perspectives using a panel of experts to conclude the opinion weights for each available option, based on the identified design elements of the energy interface.

To ensure the reliability of the expert evaluations, the Consistency Ratio (CR) was calculated for all pairwise comparison matrices. In standard AHP methodology, a CR threshold of less than 0.1 (10%) is considered acceptable, indicating logical consistency in human judgment. During the workshop, the AHP-OS platform dynamically calculated the CR for participants. If an expert's initial comparisons yielded a CR exceeding the 0.1 threshold, they were prompted by the system to review and adjust their decisions (judgments) before final submission. The final aggregated consistency ratios for the primary matrices across consumer profiles remained well below the 0.1 threshold, confirming the robust reliability of the dataset.

Figure 2 below shows outcome as design choices for non-affluent energy consumers, a three-level hierarchy table showing the relative importance rated by experts. For example, the weight given to the engagement compared to functionality, and indications which design elements should be prioritized, for example, the preference for a mobile device over a web interface.

Decision Hierarchy			
Level 0	Level 1	Level 2	Glb Prio.
Energy interface features GRP4new	Engagement 0.220	Storification (stories) 0.132	2.9%
		serious or learning games 0.073	1.6%
		system initiated interactivity (prompts tips) 0.157	3.4%
		attention-seeking smart devices 0.091	2.0%
		competition with others (leaderboards) 0.085	1.9%
		target-setting (goals and private challenges) 0.098	2.1%
		social media and sharing 0.048	1.0%
		real world rewards 0.269	5.9%
		virtual rewards (badges or points) 0.048	1.0%
	Interfaces 0.142	smart devices 0.178	2.5%
		mobile devices 0.372	5.3%
		web 0.277	3.9%
		broadcast (TV or radio) 0.173	2.5%
	Functionality and features 0.105	interface customization 0.069	0.7%
		consumption statistics 0.216	2.3%
		production statistics 0.110	1.2%
		historical costs 0.172	1.8%
		energy production management 0.133	1.4%
		smart device control 0.119	1.3%
		pre-configured simpler views 0.181	1.9%
	Limitations 0.193	cost (purchase) 0.492	9.5%
		cost (internet) 0.207	4.0%
		integration and installation difficulty 0.302	5.8%
	Usability and UX 0.340	clear prompts and interfaces 0.149	5.1%
		match between system and real world 0.091	3.1%
		error prevention 0.171	5.8%
		learnability and ease of use (consistency or 0.240	8.2%
		flexibility and efficiency of use (shortcuts 0.095	3.2%
		aesthetics and minimal design 0.096	3.3%
		user help (error recovery diagnostics document 0.157	5.3%
			1.0

Figure 2. Percentile rating by experts for energy interface design elements.

To conclude the opinion on design elements, the study was conducted on two rounds, with the first round, the expert focused on the consumer with a “non-affluent” background, while in the second round, experts viewed design elements from the “tech-savvy” energy consumers’ point of view. Figure 3 below shows the result of global priorities from the “non-affluent” consumers’ point of view.

The evaluation has provided valuable insights that support the study’s main ideas. For experts on non-affluent consumers, considering the importance of finance, ease of use, and low purchase cost emerged as critical factors influencing their preferences and decision-making. This underscores the importance of offering affordable and user-friendly options for the rural demographic. In contrast, experts’ opinion on tech-savvy and affluent background energy consumers is a strong need for advanced technological features, particularly in mobile devices and smart home integration. Their priorities

Consolidated Global Priorities

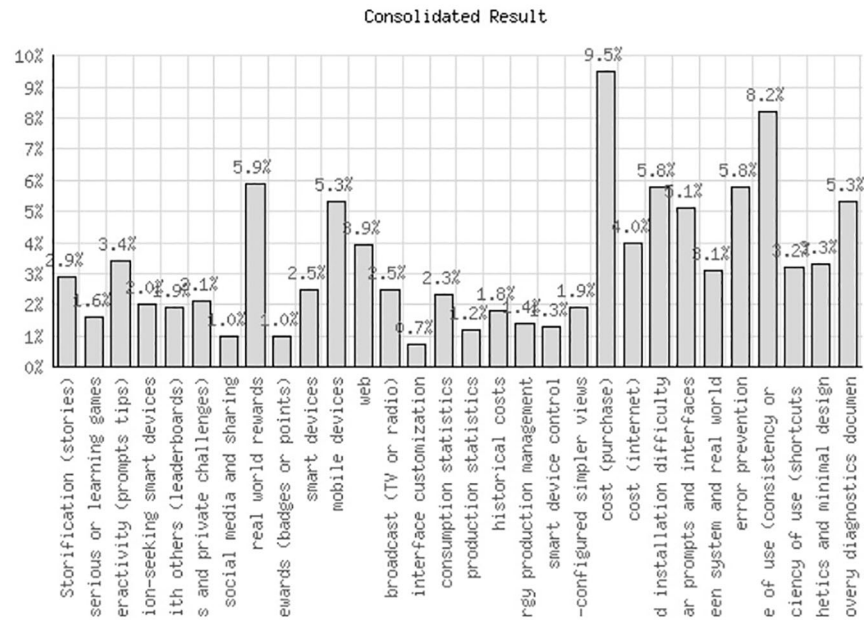


Figure 3. Energy interface design elements for non-affluent.

Consolidated Global Priorities

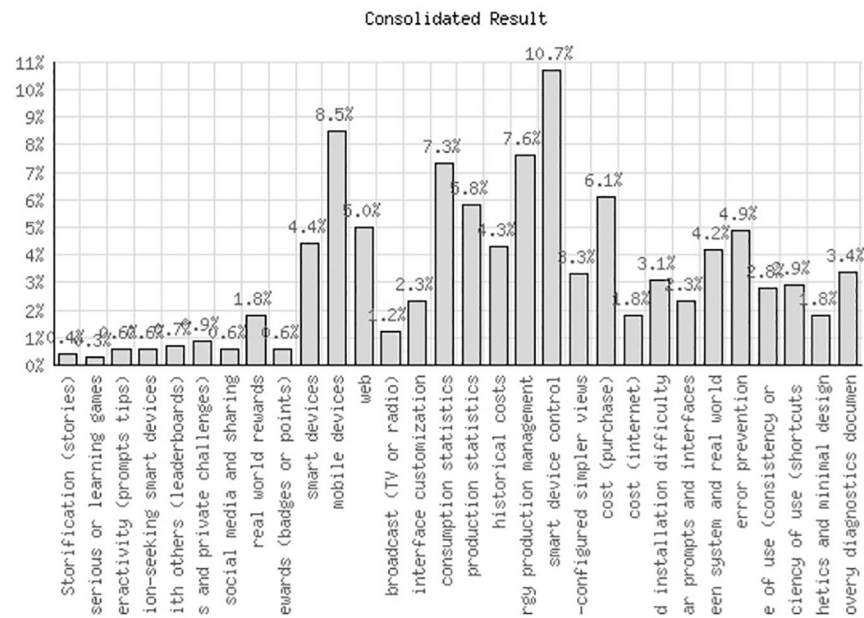


Figure 4. Tech-savvy approach on energy interface design elements.

reflect a desire for seamless connectivity and the latest technological advancements to enhance their everyday lives (see Figure 4 above). These findings highlight the distinct needs and values of rural area energy consumers from an expert perspective.

Sensitivity Analysis and Model Robustness

To evaluate the stability and robustness of the decision-making model, a sensitivity analysis was conducted using the AHP-OS platform. By incrementally adjusting the weights of the primary Level 1 criteria (e.g., simulating a shift in the importance of 'Limitations' or 'Usability'), we observed the resulting impact on the global priorities of the Level 3 design choices. The analysis revealed that the highest-ranking alternatives such as, the preference for mobile device platforms and the prioritization of purchase cost have been remained stable across minor weight fluctuations. No significant rank reversals occurred among the top design choices, confirming that the study's conclusions are robust and not overly sensitive to slight variations in expert judgment.

To evaluate the stability and robustness of the rankings under different weight scenarios, a sensitivity analysis was conducted using the AHP-OS platform. By incrementally adjusting the weights of the primary Level 1 criteria (e.g., simulating a shift in the baseline importance of 'Limitations' or 'Usability'), we observed the resulting impact on the global priorities of the design choices. The analysis revealed that the highest-ranking alternatives specifically the preference for mobile device platforms and the prioritization of purchase cost remained stable across these varying weight scenarios. No significant rank reversals occurred among the top-tier design choices, confirming that the model's conclusions are robust and not overly sensitive to slight variations in expert judgment.

Discussion

The aim of this study was to create a structured approach for understanding the data generated by previous research on energy interface design. Specifically, it focused on consumer preferences in energy data visualization, analyzing their choices and the reasons behind those choices, such as different energy profiles and heating needs. Our analysis was conducted from the perspectives of engineers, software developers, and experts, who considered user interface elements, their significance, and usability for energy consumers. As energy consumers themselves and residents of the same area with similar ethical backgrounds, their perspectives also reflect those of the energy consumers.

Given the diverse opinions among energy consumers in rural areas regarding various aspects of energy interface design, the results of this analysis offer valuable guidance to developers in creating effective energy interfaces. The Analytic Hierarchy Process (AHP) framework combines mathematical and psychological principles by integrating human input into the decision-making process. This results in weighted opinions on suitable elements for energy interfaces that are not only visually appealing but also enhance usability.

Design choices of rural and urban energy consumers

To address the first research question, RQ1, "What design principles and software features are most suitable for various demographic groups based on their unique needs?", we examined the related data provided by earlier studies conducted in the same region. We identified the recommended design elements that can be used to create an energy interface and developed a hierarchical structure of these design elements. The hierarchical structure is divided into Interactivity, Interface, Features, Limitations, and Demographics categories. Each of these categories then includes sub-categories and is further divided into design elements of energy interface based on preferred data visualization. This layout not only serves as a foundation for further analysis but also categorizes consumers' energy data visualization.

The visualization preferences of energy data also reflect consumers' energy consumption behaviors. For example, consumers with access to city heating are less inclined to search for cheaper energy, as their main electricity consumption is already covered by heating. To those who rely on electricity for heating, a small amount makes a big difference. Similarly, those who live in urban areas face the lack of incentive to invest time in searching for savings, which results in minimal financial benefit. In contrast, consumers in rural areas are more motivated, as even small savings can accumulate to a significant amount over time. In our interview study, participants explained how even a few cents lower energy costs can lead to substantial savings by the end of the winter season.

Energy consumption patterns in Finland vary between urban and rural residents due to their different living environments. These factors also influence their preferences for software features and design elements in energy data visualization, with their choice of energy-related information being heavily influenced by the local cultural environment. For example, in rural areas, households often depend on traditional energy sources, such as oil and wood, since they do not have centralized heating systems. This isolation promotes self-sufficiency and encourages the exploration of alternative energy solutions, like solar power and battery storage, especially because rural homes typically have more space available. This lifestyle also impacts their energy data visualization in a way that they tend to look for cheap energy contracts; for them, the most important element of the energy interface can be today's electricity price.

Urban residents, on the other hand, benefit from centralized heating systems provided by municipalities, which offer affordable and convenient heating and hot water services, often included in their rent. This arrangement allows them to

focus less on energy costs. In contrast, rural consumers prioritize affordability in their energy choices and tend to concentrate on financial aspects. Some urban consumers, who are more inclined toward innovation, often explore advanced energy technologies like geothermal heating, emphasizing efficiency and sustainability instead of merely aiming to save energy; they seek innovative solutions. Tech-savvy and urban energy consumers see energy data differently, and their energy data preferences differ from those of rural residents. These energy consumers mostly look for advanced integration of IoT devices into the energy interface.

Designing an energy interface requires careful consideration of the unique needs of consumers in rural and urban areas. This includes understanding their demographics, the types of energy contracts they hold, and their specific heating systems for both water and space. An effective energy interface that blends data visualization and user-centric design principles with the primary goal of empowering energy consumers and local culture by focusing on what is most important to them, rather than simply displaying energy data.

Design elements in energy applications

RQ2 was more focused on the fact that designing an energy interface requires careful consideration of the unique needs of consumers in rural areas. To answer this question, we used a co-creation activity using the AHP framework, where consumers and experts collaborate to determine which elements best suit their specific needs. The result shows that preferences for energy interface design elements fall into two main categories. Both correspond to two main consumer groups in our target rural area. The first group tends to value financial elements, including cost reduction and incentives. They focus on design elements showing financial gains, while networking, progress sharing, and leaderboard competitions are lower priorities for them. In contrast, the second group recommends prioritizing the use of technologies. There is, however, some agreement between both sides. Both agree that energy interface design should prioritize the delivery of energy-related data. Both also value interface customization, matching the energy consumers' profile and the inclusion of historical energy data, as well as ease of use.

Key findings can be categorized according to the Interactivity, Interfaces and Features. The analysis reveals significant differences in opinions across these main categories.

- **Interactivity:** The energy-saving perspective emphasizes the importance of incentives, such as real-world rewards, with a weight of 5.9%. Tech heavy view also shows importance on real world incentive with the weight of 1.8%.
- **Interface platform:** Both energy-saving and tech-heavy viewpoints place some emphasis on mobile devices as platforms for energy interfaces, with opinion weights of 5.3% and 8.5%, respectively. This is in comparison to other platforms like the Web or Television which was quite low in both opinions.
- **Features:** The tech-heavy opinion favors the use of features like smart device control, which received the highest opinion weight at 10.7%. Conversely, the non-affluent consumer want features such as consumption statistics (7.3%) and historical cost (4.3%).

The table below outlines the design elements and opinion analysis from two perspectives, along with design choices from the software engineering viewpoint (see Table 2). The first column, "Design Elements," categorizes the list based on existing data regarding energy data visualization. The second column is split into two sub columns, representing the perspectives of two different energy consumer groups. The third column presents the design choices from the developer's perspective, intended for use in creating energy interface designs.

Rural area energy consumers in our study, mainly divided into two categories based on their approach to energy monitoring. The first group emphasizes the importance of affordable solutions and highlights the financial benefits of energy data, particularly in terms of cost savings, such as different prompts displayed in the energy interface about current price and incentives. The second group advocates technical solutions aimed at reducing expenses, like the use of solar panels, including a strong understanding of advanced technologies, and prefers options that grant them greater control over energy management through an energy interface. Thus, the second group advocates a more technical and management-oriented approach, while the first group takes a more traditional view, seeking financial incentives.

Design recommendations for the first group of energy consumers require energy application to understand their preferences, for instance, doing things such as scheduling laundry, baking, or charging electric vehicles based on expected energy price. The better the application facilitates achieving these goals, the more effective it will be for example, connects users to current energy prices and provides control over their energy spending. This will enhance their ability to respond significantly as some people actively change their energy consumption routines, while others modify

Table 2. Summarizing the result of AHP analysis.

Design elements	AHP Opinions		Design choices
	Tech Heavy	Non-affluent	
INTERACTIVITY	Smart devices		Integrated control of other IoT devices, live energy statistics, EV charging status
	Energy statistics		Energy production in Kwh from solar panel or other means, transfer to grid statistics in Kw
		Incentives	Energy saving rewards, bonuses options such as free hours, energy saving programs, cheap and expensive electricity hours alerts
PLATFORM	Mobile device	Mobile devices	App for mobile devices, internet connectivity, simplicity in use, easy to use interface, easy to understand, clear visuals
FEATURES	Customization		Energy profiles based on individual preferences, prompts to configure dynamic energy interface
		Historical cost	Prompt displaying current energy price, future energy price, statistics charts, energy consumption prompts, current bill

their usage during periods of lower prices. In both scenarios, consumers prefer to monitor the market, particularly future energy prices, as this helps them adjust their energy consumption.

Design recommendations for tech-savvy energy consumers, who prioritize the integration of their modern devices, include the features such as the ability to control their energy production and connect with other IoT devices. Many consumers appreciate the possibility of integrating advanced features that allow them to enjoy the benefits most important to them, such as monitoring energy consumption for specific appliances or parts of their homes. The level of concern and understanding may vary greatly among this group when it comes to selecting an energy interface. For some consumers, it can be a “make or break” factor for their satisfaction if the energy application cannot control IoT devices; for others, it may not be very critical if the energy application does not provide an EV charging function.

Regardless of whether consumers are focused on cost-saving measures or technological integration, three core factors remain crucial for all rural area energy consumers. The first is the ease of use, including how straightforward the energy interface is to operate. The second is the functionality of how easily consumers can access the necessary information, which matches their energy profiles. The third is the reliability factor involving the energy application’s ability to operate consistently and without failure. These consumer preferences are essential for their energy data visualization, and an important factor to note is that for manufacturers and utility companies, providing seamless, reliable, and valuable integrations is no longer an optional feature; it has become a critical competitive advantage.

Conclusions

The study utilized the Analytic Hierarchy Process (AHP) framework, engaging a panel of experts to evaluate the design element of energy interface. The study also presented a three-level design choices table, which was created from previously available data. The panel of experts used that information for analysis and evaluated various user interface elements of the energy interface for rural populations. This includes the essential priorities of energy consumers for energy data visualization. The expert also looked into other related factors impacting rural area energy consumers, including their contracts, heating systems, local culture, and norms. The result revealed key insights into points such as energy consumers’ affordability and usability. Also, consumers’ preference for the use of advanced technologies, particularly with IoT devices and smart home integration.

To engage all stakeholders, this study utilized a user-centric design approach that facilitated collaboration between software engineers and energy experts to ensure that the outcomes addressed the needs of both developers and energy consumers. The primary goal of this research was to highlight the essential components of energy interfaces that not only improve usability but also resonate meaningfully with all stakeholders, including energy consumers and software developers. By shifting from a “we know best” approach to fostering a collaborative partnership. The results highlight the key design elements and provide a design perspective for both energy consumers and developers.

Expert opinion from the local community is not just important but essential when developing software for local energy consumers, as it bridges the critical gap between technological capability and efficacy on cultural elements. Without the opinion input from domain experts, such as electrical engineers, energy consumers, and software developers, the final user interface for energy consumers risk failing to address core challenges like cultural issues and consumer adoption barriers. Expert insight ensures the software is grounded in physical realities and aligns with the energy consumers need, ultimately benefiting the communities they are intended for.

Limitation and future work

The outcome of the study derived from the available data and qualitative judgments from a available number of experts. The amount of available data may influence the results, especially when evaluating and prioritizing multiple criteria, as this process is constrained by both the data and the number of experts involved. Expanding the research area to include a broader demographic could yield more comprehensive qualitative results. However, this limitation creates challenges for the study and restricts the generalizability of the findings to a wider population and different geographic contexts.

Additionally, the expert panel was assembled using convenience sampling from within LUT University. While convenience sampling inherently carries a risk of institutional bias or ‘groupthink,’ this was avoided by ensuring the panel comprised experts from highly distinct and diverse disciplinary backgrounds. As outlined in the methodology, the panel included specialists in community software engineering, energy networks and markets, energy interactions, and researchers, energy consumers. This cross-disciplinary diversity ensured that multiple, sometimes competing, perspectives were represented in the pairwise comparisons. Nevertheless, future studies should aim to include a broader geographic and institutional demographic to validate these findings further.

The study provided design choices for the user interface targeting energy consumers living in rural areas. Using the study’s outcome, software developers can make informed and effective decisions to enhance the user experience. By following the rigorous evaluation and prioritizing user requirements, the study outcome helps in creating designs that better meet not only user needs and preferences but also lead to higher satisfaction for energy providers and developers. Software developers and researchers can use the results as a foundation to explore the topic further, as well as use these results as a basis to delve deeper into the topic and as a reference for related studies.

Ethics approvals

All previous articles in the series¹ have publicly available data and written informed consent, followed by the recommendations of TENK ([Guidelines for ethical review in human sciences](#), 2019). This study utilizes publicly available data from the mentioned studies, and the panel members involved are professional researchers employed by LUT, rather than human subjects as defined by TENK. This study does not require ethical approval; the Extended data contains confirmation from the LUT Ethics Committee (see extended data, confirmation from the LUT Ethics).

Data availability

Underlying data

ZENODO: Exported data from the AHP-OS project for the study on recommendations for energy interface design.

<https://zenodo.org/records/18046536> (Qureshi, 2025).

The underlying data includes project and result exports in CSV and JSON format for each set. The only modification made is the anonymization of participants’ names, which have been replaced with identifiers ranging from PPA to PPQ. Here, “PP” stands for project participants.

1) Nonsavvy, nonaffluent

- filename: eka3AL-AHP-project_nonsavvy_nonaffluent_highlyimpacted.JSON.
- filename: eka3AL-AHPgResult_nonsavvy_nonaffluent_highlyimpacted.csv.

¹Qureshi, M., Knutas, A., & Wolff, A. (2024, May). Consumer Energy Interface Use and User Behavior Analysis During a Price Hike: A Qualitative Study. In 2024 47th MIPRO ICT and Electronics Convention (MIPRO) (pp. 1877–1882). IEEE. Qureshi, M., Knutas, A., & Wolff, A. (2025, June). Exploring Interface Design for Energy Data Visualization: A Usability Testing Workshop. In 2025 MIPRO 48th ICT and Electronics Convention (pp. 1484–1489). IEEE.

2) Techsavvy

- filename: JYBUqa-AHP-project_techsavvy_highlyimpacted.JSON.
- filename: JYBUqa-AHPgResult_techsavvy_highlyimpacted.csv.

Data are available under the terms of the Creative Commons Zero “No Rights reserved” data waiver (CC0 1.0 Public domain dedication).

Extended data

ZENODO: Exported data from the AHP-OS project for the study on recommendations for energy interface design.

<https://zenodo.org/records/18046536> (Qureshi, 2025).

The extended data includes a table used for evaluation during the AHP analysis by the expert, and the

1) Table used for evaluation during AHP analysis by the experts.

- filename: variables v3 1.xlsx.

2) Briefing slides, which guide the AHP process and facilitate the gathering of participants’ consent.

- filename: briefing and concent request slides.pdf.

3) Confirmation from the LUT Ethics to Prof Antti Knutas (Co-author in the study).

- filename: Ethical Review System email certificate.pdf.

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Open Peer Review

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Version 2

Reviewer Report 21 July 2026

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Omid Fatahi Valilai 

Constructor University Bremen, Bremen, Germany

The manuscript addresses a relevant problem concerning the design of household energy interfaces for rural consumers in cold-climate regions. The attempt to connect earlier qualitative findings with a structured multi-criteria decision process is potentially useful. Nevertheless, the present contribution remains methodologically underdeveloped and only incrementally novel. The study essentially converts interface attributes identified in the authors' earlier work into AHP priorities based on judgments from fourteen convenience-sampled participants affiliated with the same university. The construction of the hierarchy, elicitation and quantification of judgments, expert aggregation, consistency assessment, uncertainty analysis, and empirical validation are not reported with sufficient precision. More importantly, the manuscript repeatedly interprets expert judgments as consumer preferences, although rural consumers did not directly perform the AHP evaluation. Several additions in Version 2 appear to respond to the previous reviewer's concerns, but they remain largely declarative and are not supported by matrices, numerical consistency results, sensitivity outputs, or user validation. I therefore recommend **major revision** before the manuscript can be considered scientifically reliable.

The claimed novelty is currently framed as applying AHP to reconcile rural consumer and software developer priorities. However, AHP has already been applied directly to user preference prioritization in home energy management systems. Research studies have used AHP with survey information to prioritize functionality, cost, and carbon-related preferences. The manuscript does not cite or differentiate itself from the closely related contribution.

The authors should provide a structured comparison table containing:

1. Application context and geographical scope
2. Participants and sample size
3. Interface or energy-management functions
4. Criteria-identification method
5. Decision-support or statistical method
6. Validation approach

7. Reported limitations

8. Specific advancement offered by the present study

The literature review is largely descriptive, brief, and heavily dependent on the authors' previous conference publications. It does not critically compare alternative interface-design, eco-feedback, behavioral, co-design, or decision-support approaches.

The manuscript states that the hierarchy was derived from earlier interviews, usability workshops, discomfort points, and frequently cited interface elements. However, the transformation from qualitative data into AHP criteria is not documented.

The authors should report:

- Number and nature of the underlying interviews and workshop participants
- Coding methodology and codebook
- Number of initial codes and themes
- Inclusion and exclusion criteria for AHP attributes
- Frequency, salience, or theoretical basis used to retain each criterion
- Procedures for merging overlapping constructs
- Researchers involved in coding and reconciliation
- Mapping from qualitative quotations to hierarchy nodes
- Evidence that thematic saturation was achieved

The model mixes interface qualities, platforms, behavioral mechanisms, technical functions, constraints, and user characteristics in the same hierarchy. For example:

- "Smart devices" appears under both interactivity and interfaces.
- IoT integration, mobile platforms, and device control are strongly interdependent.
- Cost and complexity are development constraints, whereas human behavior and cultural differences are contextual variables.
- Usability, reliability, incentives, gamification, and energy statistics belong to different construct levels.

RQ1 asks which principles and software features are suitable for different demographic groups. However, the current study does not collect judgments from those demographic groups. Experts are asked to imagine two consumer profiles.

RQ2 asks which design elements software developers and engineers find appropriate. Nevertheless, the two reported AHP rounds concern "non-affluent" and "tech-savvy" consumer perspectives. There is no clearly separated developer-ranking model or comparison between developer and consumer judgements.

The authors should either:

1. Redefine the research questions as expert-based prioritization for two hypothetical consumer profiles, or
2. Collect direct AHP or validation data from rural consumers and separate these data from developer judgments.

Page 6 states that Level 1 matrices were exported and manually recalculated in spreadsheet software, and that these calculations "perfectly aligned" with the AHP-OS results. Page 7 then states that "No manual matrix calculation was carried out."

This is a direct methodological contradiction. The authors must state precisely:

- Which matrices were manually checked
- Who conducted the verification

- Which equations and normalization approach were used
- Numerical comparison between manual and software outputs
- Tolerance used to define agreement

The two sensitivity-analysis paragraphs on page 11 are substantially duplicated. Moreover, the section provides no numerical evidence.

A valid sensitivity analysis should specify:

- Criteria varied
- Baseline values
- Perturbation ranges
- Increment size
- One-at-a-time or simultaneous variation
- Number of scenarios
- Rank-reversal conditions
- Stability intervals for the leading alternatives
- Graphical sensitivity outputs

AHP assumes that the compared elements are sufficiently independent. This assumption is questionable because mobile interfaces, smart devices, IoT control, customization, cost, usability, and consumer behavior influence one another.

The authors should either justify the independence assumption or consider methods that accommodate interdependence and uncertainty

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and does the work have academic merit?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Industrial Engineering and operations research and decision sciences.

I confirm that I have read this submission and believe that I have an appropriate level of

expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 26 June 2026

<https://doi.org/10.21956/openreseurope.26290.r76330>

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Sathishkumar Veerappampalayam Easwaramoorthy 

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All Comments Addressed.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: I have expertise in Data Science, Machine Learning, Artificial Intelligence, and decision-support modeling, including evaluation of multi-criteria decision-making methods such as AHP, user-centric system design, and statistical validation of experimental studies. My experience also includes reviewing manuscripts involving AI-based systems, ensemble learning, data analytics, and applied computational frameworks, which directly relates to the technical assessment of this study's methodology, AHP-based analysis, and experimental design.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 08 April 2026

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- The technical contribution of the study is not clearly differentiated from previous AHP-based interface design research and should be more explicitly highlighted.
- The research gap is mentioned in general terms, but it is not supported with a structured comparison of prior studies and their limitations.
- The introduction mixes background, motivation, and methodological description, which reduces clarity and weakens the technical framing.
- The two research questions are clearly stated but their connection to the AHP hierarchy construction is not sufficiently explained.
- The study relies heavily on findings from previous studies, yet the validity and consistency of those datasets are not discussed.
- The hierarchical decision model is described conceptually but lacks formal mathematical representation and structure.
- The process used to select criteria and sub-criteria for the AHP hierarchy is not rigorously justified.
- The hierarchy levels are explained in text, but a clearer structured diagram would improve technical understanding.
- The pairwise comparison matrices used for AHP calculations are not presented, reducing transparency.
- The consistency ratio values for expert judgments are not reported, which weakens reliability.
- It is unclear whether inconsistent comparisons were identified and corrected during analysis.
- The aggregation method used to combine multiple expert judgments is not clearly described.
- The weighting approach used to compute global priorities needs more mathematical explanation.
- The exclusive reliance on AHP-OS software without manual verification reduces methodological transparency.
- Sensitivity analysis of criteria weights is not presented to evaluate stability of results.
- The robustness of rankings under different weight scenarios is not evaluated.
- The sample size of fourteen experts is relatively small for multi-criteria decision analysis.
- The use of convenience sampling may introduce bias and should be more carefully justified.
- The expert panel composition lacks balance across software engineering and energy domain experts.
- The study does not report inter-rater agreement among expert participants.
- The demographic details of experts are not fully described, limiting reproducibility.
- The decision scale from 1 to 9 is mentioned but not formally justified.
- The eigenvector computation process is explained informally without equations.
- The normalization procedure used in AHP is not mathematically described.
- The study does not include validation using an alternative multi-criteria method.
- No comparison with other MCDM techniques such as TOPSIS or PROMETHEE is provided.

- The results are presented descriptively without statistical interpretation.
- The percentage weights are reported but their significance is not discussed.
- The difference between consumer groups is not statistically analyzed.
- The study does not evaluate uncertainty in expert judgments.
- The AHP hierarchy appears complex, but dimensionality reduction is not discussed.
- The criteria independence assumption of AHP is not addressed.
- The study does not discuss potential rank reversal issues.
- The model does not include validation using real user testing.
- No prototype implementation of the proposed interface is presented.
- The practical deployment scenario of the energy interface is not evaluated.
- The findings rely solely on expert opinion rather than empirical performance.
- The study does not include usability evaluation metrics.
- No experimental validation with rural consumers is conducted.
- The generalization of results beyond Finland rural context is limited.
- Cultural bias in expert judgments is not discussed.
- The discussion section largely repeats results without deeper analysis.
- The link between research questions and results is not clearly structured.
- The decision-making implications for developers are not quantitatively explained.
- The limitations section briefly mentions sample size but lacks methodological depth.
- The reproducibility of the study depends heavily on external datasets.
- The data repository is referenced but preprocessing steps are not detailed.
- The workflow from previous studies to AHP modeling is not formally defined.
- The conclusion summarizes findings but does not quantify performance improvements.
- Overall, the technical novelty of combining expert judgment with prior qualitative data should be more rigorously demonstrated.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and does the work have academic merit?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: I have expertise in Data Science, Machine Learning, Artificial Intelligence, and decision-support modeling, including evaluation of multi-criteria decision-making methods such as AHP, user-centric system design, and statistical validation of experimental studies. My experience also includes reviewing manuscripts involving AI-based systems, ensemble learning, data analytics, and applied computational frameworks, which directly relates to the technical assessment of this study's methodology, AHP-based analysis, and experimental design.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
