# Innovating the way out of the energy crisis: Commercialization pathways of home energy management user-innovations

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***Abstract*—User innovations can have a significant impact on new and rapidly evolving markets of technologies, such as home energy management systems (HEMS). This study explores user innovators' motivations, innovations, scalability potential, and addresses key aspects of business model design during the commercialization process. The data for this research was collected with semi-structured interviews with individual users and solution providers in Finland during the energy crisis in 2022-2023. The availability, installation, and interoperability of complementary products play a pivotal role in the commercialization and scalability of HEMS innovations. Additionally, commercialization strategies must strike a balance between hardware and software-based solutions.**

***Index Terms*—Commercialization, Demand Response, Home Energy Management System, Technology Acceptance, User Innovation**

## I. Introduction

The energy crisis of the winter of 2022-2023 created price spikes that lead many customers into trouble. Governments aimed to soften the financial burden with different policy measures, such as price caps, windfall profit regulation, and tax breaks [1]. Finland did relatively few support policies, and mostly they came rather late. This meant that many customers experienced the energy crisis in a critical way, especially when they had to renew their electricity contracts during the price spike months. A large portion of the electricity retailers offered only spot price contracts, which meant that many people also faced the dynamic pricing model [2]. In August 2022, for example, there were 8 days with spot prices above 40 €c/kWh, the average price being 26 €c/kWh. In December 2022, there were 14 days with prices surpassing 30c€/kWh [3].

The positive side of the crisis was that it induced customer-side interest and innovations in energy consumption, home energy management, and self-consumption. This context provides an interesting space to research user innovations related to home energy management systems.

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The existing literature on HEMS-related user innovation has identified different roles that users play in innovation adoption and up-scaling. From a socio-technical perspective, these include user-entrepreneurs, user-legitimators, user-intermediaries, and user-citizens [4]. In the HEMS context, users are sharing knowledge, customizing the solutions, programming and controlling the appliances in different ways, integrating different solutions within a community, and even co-designing the related smartphone apps with open source code [5]. Some user innovations can be commercialized and developed into business ideas and business models, through existing companies, start-ups, or diffusion among peers [6]–[8].

Despite the potential of HEMS for decarbonizing our energy systems, their takeoff has been relatively slow. Major barriers to adopting it are linked to transaction costs: the level of associated complexity and effort, as well as the risks and lack of perceived control, hinder the both demand and supply sides of the market [9]. Essentially, HEMS is a configurational innovation: its adoption means integrating a generic innovation with the local elements [10]. We study HEMS user innovations and their commercialization characteristics, especially the constraints and potential for scalability. Newly established solutions are also studied to find how they have been designed for commercial purposes by user entrepreneurs and manufacturers. The research question of this study is: *What home energy management user innovations are and how they can be commercialized?*

This paper is structured in the following way. First, the background of the related literature is presented. Second, the methodology is broken down, followed by the results and then a discussion. Finally, the study is concluded, and some ideas for future work are offered.

## II. Theoretical Background

### A. User innovation and communities

Traditionally, innovation and new product development have only been seen as activities and processes led by manufacturers. However, a significant stream of literature research has revealed that innovation also has a place in communities of regular users, and their actions often precede those of the manufacturers [11]. They have been found to develop or modify different consumer products, for example, sports equipment [12]. User innovators can be identified as lead users, a concept established in the 80s by von Hippel [13]. The characteristics of lead users include such behavior as they have high expectations of the benefits from a solution, and they are ahead of other users on an important marketplace trend. These attributes make lead users likely to innovate and create commercially attractive solutions. The needs of the lead users are likely to transfer to the masses over time. [13]

Lead users have been found to form communities around the topics of interest in various contexts, such as sports equipment, professional virtual and 3D printing communities [6], [14], [15]. Nowadays, it is more common to have online communities, some of which are very easy to join on social media or other platforms. These communities encourage knowledge sharing and social networking. Knowledge is shared to help each other, gain social capital, and out of the norm of reciprocity [14]. As for users, the general motivations to innovate are enjoyment, learning, reputation, and gaining benefits from the use itself [15]. They can benefit more if another user improves their solution based on shared knowledge and by re-mixing the existing available solutions with their own add-ins [11], [15]. Industrial actors often underestimate the importance of user-innovation, and therefore, it is interesting to study how community dynamics impact commercialization of solutions and which solutions can be commercialized.

### B. *Commercializing user innovations*

User innovation has two paths to be commercialized, either by a manufacturer or by the users themselves. Early research on user innovations showed that manufacturers were the ones who commercialize the innovations [11]. It has then been noticed that users themselves often do become user entrepreneurs depending on the field and market situation. Typically, users' main advantage over manufacturers is inside information about the market and other users. [7] This is often the case in new and rapidly evolving markets. In [6], manufacturers perceived the market as too risky and did not want to make significant irreversible investments. Four distinct periods could be identified on the commercialization path by user innovators. These were starting, forming communities, commercialization, and industrialization (incremental innovation). These were characterized by different relationships between users and sharing of information. [6] If companies aim to use user-innovators and later on commercialize innovations themselves, they can induce and steer user-innovation by introducing toolkits that make it easier [16].

The likelihood of an innovation being adopted can be estimated with scalability factors. These include aspects internal to the solution and also external ones affecting the entrepreneur. In traditional technology adoption studies, the solution is reviewed regarding perceived usefulness and ease of use. These factors have been found to correlate with the current use of a product. [17] Age, gender, income level, and education level have been noticed to result in different attitudes and preferences on different aspects of the solution [18]. It has also been noticed that modular product structures make user innovations easier to make and adopt because they are more decomposable and reconfigurable than integral products. Modular structures also give confidence to tinker with the products because the changes they make are reversible [19]. The ecosystem literature highlights end-users' complementary assets [20] like flexible loads (e.g., EVs, smart thermostats, boilers), internet connection, and smart meters are crucial in the diffusion process. Energy management often requires installing devices such as relays, so ease of use should include the whole process of installation and deployment of the solution [10].

The external factors impacting user entrepreneurship include complementary resources such as distribution channels, brand recognition, manufacturing capability, and information advantages [7]. Established manufacturers are more likely to be better positioned than users regarding the first three factors. However, users can have more information about the use cases of the solution and have less to lose. By interacting with each other, active users become more user-oriented and can create individualized solutions [6]. Whether the user should become an entrepreneur also depends on their current life situation. An enthusiast who works with the solutions a lot already is more likely to commercialize the product themselves. There are also differences in whether the user innovated the solution for their work or personal use [7]

### C. *User innovation helping to commercialize HEMS business models*

User innovation in the field of HEMS is seen as crucial because HEMS adoption happens through combining different components that users have at home [10]. Users create new combinations of microgeneration, smart appliances, energy storage, and electric vehicles (EVs). The main tasks of a HEMS include monitoring, logging, control, management, and alarm functionalities. [21] This is somewhat different from traditional user-innovation, which is often based on single products or behaviors [22]. The external environment, including smart meters, available dynamic tariffs, and the relative price of different energy sources affects the user innovation of HEMS.

In a study on a range of sustainable RE technologies, [8] differentiated pathways for user-innovation: consumer entrepreneurship, incorporation to existing products, and diffusion among peers in various forms (adding new features, partial adoption, adapting to a new brand). User entrepreneurship was linked with high innovativeness, diffusion, and energy-saving potential, compared to the ones revealed to a company.

In HEMS solutions, the related business model design choices include the value capture (pricing, costs), value proposition (target customer, value), and value delivery (value chain organization) aspects. The complexity of the solution means how many different functions of a HEMS the solution actually covers [21]. HEMS happens increasingly within an ecosystem, and creating new business models in such a multi-actor environment can be challenging [23]. Pricing is an essential part of any business model ensuring that the business can capture the value of the solution. The choices made on these different aspects form the path to commercialization of the solution.

## III. Methodology

The research consists of reviewing literature as the background, collecting, and analyzing data, and discussing the results against the literature. The data collection was conducted with semi-structured interviews in early 2023. Semi-structured interviews are helpful for exploring the topic in more detail and giving room for the interviewees' personal thoughts [24]. The interviews were organized around four themes: background information, demand response, innovations and customers, and virtual communities. This structure allowed flexibility to address various details with different participants. Different interview structures were designed for consumers and solution providers. Details of the service providers can be found in Table 1, while consumer interviews are presented in Table 2.

The interviewees were recruited via Facebook and selected based on their activity and participation in Finnish Facebook groups focusing on home energy management and smart homes. A typical interviewee was active and had developed their own solutions. Eighteen users were invited to the interviews, the seven listed below accepted, two refused, and nine did not respond. The interviews were held online, allowing for long-distance interviews, more flexible schedules, and comfortable surroundings. The interviews were held, recorded, and transcribed via Microsoft Teams. The interviews were held in Finnish.

TABLE I. Commercial innovators (CIs) interviewed

| Index | Date | Business | Age (yrs.) | Employees | Duration |
|---|---|---|---|---|---|
| *CI1* | 2.2.2023 | Consumption optimization | 0-2 | 1-10 | 49 min |
| *CI2* | 8.2.2023 | Consumption optimization | 0-2 | 1-10 | 59 min |
| *CI3* | 9.2.2023 | Consumption optimization | 6-10 | 1-10 | 76 min |
| *CI4* | 10.2.2023 | Consumption optimization | 3-5 | 1-10 | 48 min |
| *CI5* | 13.2.2023 | Consumption metering | 6-10 | 11-30 | 33 min |
| *CI6* | 16.2.2023 | Consumption optimization | 6-10 | 1-10 | 54 min |
| *CI7* | 23.2.2023 | Electrical contracting | 6-10 | 11-30 | 45 min |

TABLE II. User-innovators (UIs) interviewed

| | Date | Age group | Gen der | House type | Duration |
|---|---|---|---|---|---|
| *UI1* | 26.1.2023 | 26-35 | Male | Row house | 43 min |
| *UI2* | 2.2.2023 | 36-45 | Male | Semi-detached | 55 min |
| *UI3* | 3.2.2023 | 36-45 | Male | Detached | 59 min |
| *UI4* | 3.2.2023 | 46-55 | Male | Flat | 47 min |
| *UI5* | 6.2.2023 | 46-55 | Male | Detached | 56 min |
| *UI6* | 8.2.2023 | 46-55 | Male | Semi-detached | 58 min |
| *UI7* | 13.2.2023 | 36-45 | Male | Detached | 63 min |

The solution providers were small Finnish companies. These were selected by scanning for exciting solutions in different sources, such as newspapers, Facebook groups, and word of mouth. Most of their solutions were developed and commercialized during the last two years. One person from each provider was selected to contact, typically one of the founders. Twelve people were contacted, seven accepted, and five did not respond. One interview was held face-to-face, and others via Microsoft Teams in Finnish. The research was designed to produce descriptive and detailed data about consumers' and solution providers' solutions and development processes. The interview data is qualitative and therefore analyzed with qualitative data analysis methods. Visual and verbal data was also available but was only used to occasionally confirm the data. Thematic analysis was chosen as the analysis framework. In the thematic analysis, the data is coded and then analyzed to find themes, patterns, and relationships. MAXQDA software was used to do the detailed coding and analysis.

## IV. Results

### A. User innovations

All of the interviewed user innovators were interested in managing their consumption and had created innovative solutions. The reasons why they innovated included monetary benefits that the solutions could offer by shifting consumption to cheaper hours of dynamic pricing, environmental benefits, and participating in public good. All of them valued learning highly, and the support of virtual communities was significant. The characteristics of lead users could be identified in the interviewees. They were ahead of the trend either because of work-related needs or their personal interests. They generally also enjoyed learning from others, which motivated them to share experiences in virtual communities.

The user interviewees described 27 HEMS-related solutions, of which 18 were software-based and nine were hardware-based. Many users based their solutions on existing open-source architectures that allowed for creativity. Most of the solutions were incremental improvements rather than radical innovations. A summary of all solutions can be found in Table 3. The scalability of the solutions was evaluated based on the user's description of the solution.

Four types of functionalities could be identified as the primary purpose of the solution. These were control, monitoring, management, and support. Control solutions were clearly the most common ones, as they controlled the electricity consumption of end-users' devices. Monitoring solutions enable following the information flow from devices, temperatures, or electricity prices, for example. Support and management solutions were the least common ones, and they were used to support other solutions. Support solutions included, e.g., providing access to day-ahead prices and 3D-printed cases for microprocessors. A more considerable number of required complementary products or a more tailored design were typical constraints that reduced the scalability of a solution. One user-innovator had created a whole HEMS software and architecture by himself, and this was categorized as a management solution.

TABLE III. SCALABILITY OF USER INNOVATIONS

| Basis | Scalability | Constraints | Function | No. of solutions |
|---|---|---|---|---|
| *Soft-ware* | High | Requires common complementarities | Support / Control | 2 |
| | Medium | Requires complementarities, installation | Control / Monitoring | 9 |
| | Low | Requires rare complementarities, tailored | Control | 6 |
| | Negative | Architecture designed for the specific user only | Management | 1 |
| *Hardware* | High | Requires common complementarities | Control | 1 |
| | Medium | Requires complementarities, installation | Control | 2 |
| | Low | Requires rare complementarities, tailored | Control / Monitoring | 5 |
| | Negative | Designed for the user, installation | Support | 1 |

The most scalable solutions were easy to install and use and were interoperable on common complementarities. These included, for example, an application programming interface (API) for fetching electricity day-ahead prices. The "medium"-level of scalability included solutions such as consumption optimization with software, which required some complementary products such as relays. The hardware is typically available off-the-shelf. The third, "low"-level solutions required rarer complementarities, such as a specific type of boiler for heat optimization, installation of various sensors or using a 3D printer. The two innovations that would not scale were architectures designed for the specific user. User innovations also included 11 behavior-based innovations, but they were left outside the final study because they require much creativity to be commercialized. The scalability of behavioral innovations was still estimated to be theoretically relatively high because they were less context-specific. For example, smart plugs with monitoring screens were applied in these examples.

## B. *Solution provider innovations*

The solutions developed by the solution providers are listed in Table 4 below. Solution providers CI2, CI3, and CI4 had originally created the solution as users, becoming later on user entrepreneurs. Comprehensive turnkey HEMS-as-a-service (HaaS) solutions were the most common, and it could be mixed with aggregator or electrical contracting businesses. The solutions differed in scope, i.e., how many devices were added to the system or how many partners were needed. These resulted in different constraints or challenges for scalability, too. The easiest to install and use were solutions by providers CI3, CI6, and CI7. These also had higher prices. A higher price could offset the perceived usefulness of the solution. It was evident in some cases that the user has to trust the provider to give them control of consumption that takes place within their household. Solutions by CI2 and CI4 required complementarities such as relays or a microcomputer that would run the software. This would require more technical skills and knowledge from the user.

TABLE IV. SCALABILITY OF SOLUTION PROVIDER INNOVATIONS

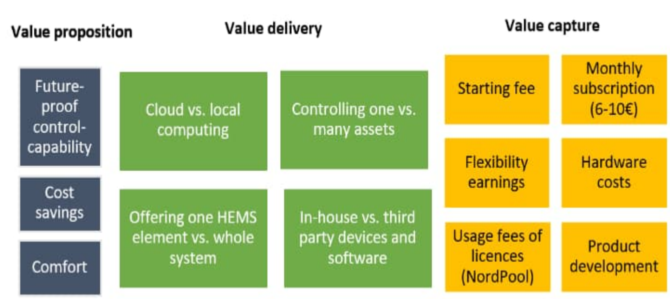
| Index | Solution | Scope | Constraints |
|---|---|---|---|
| *CI1* | HaaS / Aggregator | EV, photovoltaics | Rely on 3rd party solutions |
| *CI2* | HaaS | Heating | Requires complementarities, complex installation |
| *CI3* | Haas | Heating, photovoltaics | High price |
| *CI4* | Haas | Plugged devices | Requires complementarities, user installs |
| *CI5* | Metering | Metering devices | No control functionality |
| *CI6* | HaaS | High consumption sources | The user gives up control |
| *CI7* | HaaS / Electrical contracting | Apartment buildings | High price |

From the value delivery side, business model design questions arise on several fronts. CI1 mentioned that relying on 3rd-party software to get data and control consumption reduces control, blurs responsibilities, and there is a risk that those solutions would not work at some point. The scope of the solution also impacted the number of stakeholders involved. The solutions could include collaboration with other actors, such as electricians or electronics retailers to make the acquisition and installation as easy as possible. The choice between edge vs. cloud computing is related to the scope of the solution: in brief, comprehensive turnkey solutions, which also enable adding different functions, are operated instead on cloud by the service provider.

Related to the value proposition, service providers had different approaches. All solution providers recognized that the most crucial benefit for users is financial savings. Many also stated that the best solution is comprehensive and easy to use, also in the future. CI3 emphasized that they want to deliver a turnkey solution to ensure that they are in control of the whole process, and that everything will work.

On the value capture side, the most common pricing was a monthly fee with a starting fee. A surprisingly big cost came from the license to use NordPool data. User entrepreneurs CI2 and CI4 were not looking for profit only but wanted to deliver a solution that would help similar users. Their solutions were, however, more challenging to install.

**Fig 1.** Service providers' business model design options



## V. Discussion and Conclusions

User innovations are better suited for commercialization when they are easy to use, perceived as useful by other users [16], and compatible with common end-user assets [20]. User innovations play a significant role when the industry is new and the users have information advantages [7]. An evaluation of the market based on the interviews reveals similarities to the stage of commercialization defined in [6]. User entrepreneurs can introduce new solutions to the market, although products already exist. Within the developer communities, small teams focused on a specific problem were seen as beneficial. For companies utilizing these communities, understanding the motivations of user innovators is essential. This study aligns with the 3D printing study [15], emphasizing enjoyment, learning, use-value, with an added factor of public good in the HEMS context."

When commercializing a user innovation, the first question is who should do it. This question is narrowed to a choice between the user and an established manufacturer [7]. HEMS innovations could be software-only or include hardware. Software innovations tend to be more scalable because they benefit a wider user base. The main constraints are the requirements for complementary products and the amount of configurational work left to the customer. Even though the user-innovator likes this phase, the mainstream markets might not. Typical required solutions included relays, smart plugs, and a home automation hub. One option is to include any necessary complementary products within the solution package. This results in a make-or-buy decision that some of the solution providers interviewed had also faced. Some of the less scalable solutions were so tailored to the needs of that specific user that it would take more work to find a bigger market. In addition, a common challenge with home energy management is that the user must trust the provider when they control consumption within their home.

The context of the study is the winter of 2022-2023, which included high and volatile electricity prices in Finland. How enduring the innovations are remains to be seen; however, citizens' understanding of the energy transition accelerated significantly during the crisis. Future research could involve a longitudinal approach to track the success of user innovators' plans. A cross-country comparative study could explore the impact of varying energy subsidies on HEMS user innovation during energy crises.

## References


[1] G. Sgaravatti, S. Tagliapietra, and G. Zachmann, "National policies to shield consumers from rising energy prices," Bruegel. [Online]. Available: https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices

[2] M. Pantzar, "Pörssisähkön käyttäjien määrä kovassa kasvussa – 'Usein ainoa vaihtoehto, jos sopimus katkolla', kerrotaan Energiavirastosta," *Yle*, 19 2022. Accessed: Jul. 06, 2023. [Online]. Available: https://yle.fi/a/3-12655819

[3] NordPool, "Day-ahead prices." Accessed: Oct. 30, 2023. [Online]. Available: https://www.nordpoolgroup.com/en/Market-data1/Dayahead/Area-Prices/FI/Daily/?view=chart

[4] J. Schot, L. Kanger, and G. Verbong, "The roles of users in shaping transitions to new energy systems," *Nature Energy*, vol. 1, no. 5, p. 16054, 2016, doi: 10.1038/nenergy.2016.54.

[5] L. Gonçalves and L. Patrício, "From smart technologies to value cocreation and customer engagement with smart energy services," *Energy Policy*, vol. 170, no. May 2021, p. 113249, 2022, doi: 10.1016/j.enpol.2022.113249.

[6] C. Hienerth, "The commercialization of user innovations: the development of the rodeo kayak industry," *R&D Management*, vol. 36, no. 3, pp. 273–294, 2006, doi: 10.1111/j.1467-9310.2006.00430.x.

[7] S. Shah and M. Tripsas, "When Do User-Innovators Start Firms? Towards a Theory of User Entrepreneurship," *University of Illinois at Urbana-Champaign, College of Business, Working Papers*, Jan. 2004.

[8] S. Hyysalo, *Citizen Activities in Energy Transition: User Innovation, New Communities, and the Shaping of a Sustainable Future*, 1st ed. London: Routledge, 2021. doi: 10.4324/9781003133919.

[9] B. Parrish, P. Heptonstall, R. Gross, and B. K. Sovacool, "A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response," *Energy Policy*, vol. 138, no. August 2019, 2020, doi: 10.1016/j.enpol.2019.111221.

[10] G. W. De Vries, W. P. C. Boon, and A. Peine, "User-led innovation in civic energy communities," *Environmental Innovation and Societal Transitions*, vol. 19, pp. 51–65, Jun. 2016, doi: 10.1016/j.eist.2015.09.001.

[11] E. von Hippel, *The sources of innovation*. New York: Oxford University Press, 1988.

[12] S. K. Shah, "From Innovation to Firm Formation: Contributions by Sports Enthusiasts to the Windsurfing, Snowboarding & Skateboarding Industries," in *The Engineering of Sport 6*, E. F. Moritz and S. Haake, Eds., New York, NY: Springer, 2006, pp. 29–34. doi: 10.1007/978-0-387-45951-6_6.

[13] E. von Hippel, "Lead Users: A Source of Novel Product Concepts," *Management Science*, vol. 32, no. 7, pp. 791–805, Jul. 1986, doi: 10.1287/mnsc.32.7.791.

[14] C.-J. Chen and S.-W. Hung, "To give or to receive? Factors influencing members' knowledge sharing and community promotion in professional virtual communities," *Information & Management*, vol. 47, no. 4, pp. 226–236, May 2010, doi: 10.1016/j.im.2010.03.001.

[15] M. A. Stanko and B. J. Allen, "Disentangling the collective motivations for user innovation in a 3D printing community," *Technovation*, vol. 111, p. 102387, Mar. 2022, doi: 10.1016/j.technovation.2021.102387.

[16] E. von Hippel, *Democratizing innovation*. Cambridge, Massachusetts; London, England: The MIT Press, 2005.

[17] F. Davis, "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology," *MIS Quarterly*, vol. 13, p. 319, Sep. 1989, doi: 10.2307/249008.

[18] J. Shin, Y. Park, and D. Lee, "Who will be smart home users? An analysis of adoption and diffusion of smart homes," *Technological Forecasting and Social Change*, vol. 134, pp. 246–253, Sep. 2018, doi: 10.1016/j.techfore.2018.06.029.

[19] T. H. Chan and S.-Y. Lim, "The Emergence of Novel Product Uses: An Investigation of Exaptations in IKEA Hacks," *Management Science*, vol. 69, no. 5, pp. 2870–2892, May 2023, doi: 10.1287/mnsc.2022.4486.

[20] M. G. Jacobides, C. Cennamo, and A. Gawer, "Towards a theory of ecosystems," *Strategic Management Journal*, vol. 39, no. 8, pp. 2255–2276, 2018, doi: 10.1002/smj.2904.

[21] B. Zhou *et al.*, "Smart home energy management systems: Concept, configurations, and scheduling strategies," *Renewable and Sustainable Energy Reviews*, vol. 61, pp. 30–40, Aug. 2016, doi: 10.1016/j.rser.2016.03.047.

[22] K. Borner, H. Berends, F. Deken, and F. Feldberg, "Another pathway to complementarity: How users and intermediaries identify and create new combinations in innovation ecosystems," *Research Policy*, vol. 52, no. 7, p. 104788, Sep. 2023, doi: 10.1016/j.respol.2023.104788.

[23] L. A. Hale, "Courtship for business model innovation: Early stage value negotiation for the sustainability of smart homes," *Journal of Cleaner Production*, vol. 297, p. 126610, 2021, doi: 10.1016/j.jclepro.2021.126610.

[24] W. C. Adams, "Conducting Semi-Structured Interviews," in *Handbook of Practical Program Evaluation*, John Wiley & Sons, Ltd, 2015, pp. 492–505. doi: 10.1002/9781119171386.ch19.