Materialization of households' participation in Swedish smart energy grid demonstration projects

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Abstract

Developing a low-carbon energy system requires far-reaching societal transformations, not least in end user's energy practices and behaviours. Smart energy grids have recently gained attention among national governments as a potential solution for low-carbon energy transitions at the household level as they are assumed to empower energy consumers and make them an active part of a more balanced and efficient energy system with a high share of renewable electricity produced at local level. The aim of this paper is to investigate the ways in which developers attempt to influence household behaviour through the use of devices for signalling and demand side response. Interviews with technology and project developers of four smart energy grid projects in Sweden (READY, InteGrid, InterFlex, and FLEXICIENCY), and reviews of developer's reports and presentations were done to investigates how technology and project developers try to use devices as intermediaries in order to increase household participation in smart energy grid projects and change their energy-consuming practices. The result showed that developers primarily focus on the functionality of their devices and user interfaces. They take into account several factors when designing technologies to encourage households to engage in smart energy grid projects. These factors include the amount of effort required from households, attractiveness of engagement in energy use management, and additional values (other than increasing sustainability of energy behaviours) offered by devices. However, the study revealed that developers often fail to apply holistic approaches that address not only technological factors but also social and cultural barriers to technology adoption.

1 Introduction

Sweden's net-zero energy goal and sustainability targets are calling for a systematic change in the current energy system (Millot et al., 2020). Swedish targets for the energy system include 50 percent increase in energy consumption efficiency by 2030 and achieving 100 percent energy production from renewable sources by 2040 (Swedish Energy Agency, 2021). To meet these sustainability targets innovative approaches and technologies are needed for enhancing sustainable use and production of energy in all sectors (Assefa and Frostell, 2007). Households, due to a share of around 34 percent of annual total energy use in Sweden can play an important role in sustainable energy transition (SCB, 2022a, SCB, 2022b). In recent years, there has been an increasing interest in smart energy grids focusing on sustainable energy use and management (Rohde and Hielscher, 2021). Smart energy grids are electricity networks that influence the demand for electricity via a two-way digital communication. It integrates power supply with communication technologies for enabling Demand Side Response (DSR) to increase efficiency and reliability of energy grids (Kopsidas and Abogaleela, 2018).

DSR allows bottom-up contribution of end-users such as households in peak load reduction. This bottom-up contribution is usually through offering flexibility in use of energy during peak hours (Chakraborty et al., 2020), i.e. balancing the electricity system through, for example, shifting the time of energy use of home appliances to times with lower demand. DSF thereby also helps integrating renewable energy into energy grids by better matching production and consumption patterns (Söder et al., 2018).

Demand-side flexibility requires active engagement of households and may result in a disruption of everyday life routines. Smart energy grids are assemblages of various type of technologies in renewable energy production, digital sensing, smart metering, remote monitoring, automation, etc. They are supposed to influence households' practices through feedback mechanisms designed to change in household's energy behaviour by communicating their financial and environmental impacts. There is an increasing body of literature reviewing the potential of smart energy grids (Thornbush and Golubchikov, 2021, Rohde and Hielscher, 2021), impact of demand-side flexibility on energy systems (Rinaldi et al., 2022, Torriti, 2015, Smale et al., 2017) and technical solutions (Wagner et al., 2010, Hasankhani et al., 2021, Uslar et al., 2019). While a number of studies have suggested that the impact of energy-saving devices has been limited in terms of promoting participation in smart energy grid projects (Christensen et al., 2020), little research has been conducted to explore why designers continue to rely on such devices and how they perceive their impact on user engagement. The aim of this paper is to investigate the ways in which developers attempt to influence household behaviour through the use of devices, despite evidence from previous studies suggesting that the efficacy of such devices is limited. Previous research has studied households' motivation in engaging with smart energy grid technologies (Skjølsvold and Ryghaug, 2015, Hansen and Hauge, 2017); and changes in their practices (Naus et al., 2015, Christensen et al., 2020). However, the impact of smart energy grids and the eco-system of devices connected to it, such as smart meters and apps for visualising costs or energy consumption, significantly depends on how project and technology developers understand and interpret the way such devices influence and shape the behaviour and participation households which in turn results in particular strategies and design choices. The underlying assumption seems often to be that certain characteristics of these devices create affordances to use them and behave in particular ways (Gibson, 2014, Clapham, 2011). This paper investigates how technology and project developers understand the role of devices in enabling household participation in the energy transition and how this understanding is translated into choices for design of consumer-related objects and devices used in smart energy grid pilot projects in Sweden.

After introducing the methods used and the case studies the next section, we provide an overview of the conceptual framework that underpins our empirical analysis. Section four presents the findings of our study, and each subsection concludes with a discussion of the results.

2 Methodology

In this study the material enactment of household engagement in smart energy grid demonstration projects was analysed in four case studies in Sweden. The focus of the study was on the assumed agency of devices (e.g., smart home appliances, energy use monitoring and controlling devices, steering devices, data, solar panels, etc.) in enrolling and actively engaging households in these projects. To study the role of materials in these processes, interviews with a total of 13 project developers and project managers were conducted (See Table S1 in the appendix). The interviews were done between September 2020 and April 2021. Interviews were done, in person or online. Except three interviews, all interviews were recorded and transcribed. Three interviewees didn't want the interview to be recorded and instead detailed interview notes were taken. The semi-structured interviews were guided by questions around the technologies that were used in the projects, strategies for household engagement, design choices, feedback mechanism used in the project and the influence of the project on households' energy consumption. Additionally, documents such as project reports and official project presentations of the four projects were analysed. The focus of these analyses was on identifying the technologies used in feedback mechanisms, engagement approaches and the effectiveness these approaches in different project. A list of documents that were analysed are shown in (Table S2 in the appendix). The documents, transcripts and interview notes were analysed with the support of NVivo 12 software.

2.1 Case studies

To identify cases for our study, we first compiled a list of Swedish smart grid demonstration projects by conducting an internet search. We then examined project websites and publicly available reports to narrow down the list to projects with a focus on demand side response or household engagement. We reached out to the contact persons of the shortlisted projects and selected four cases that were most relevant for our research based on initial findings. The chosen cases, namely READY, Flexiciency, InteGrid, and InterFlex, had a strong emphasis on household engagement and were further investigated.

2.1.1 READY

This project was started in 2012 and had a vision to decrease energy consumption of 300 apartments to half thought effective communications with the tenants. The READY project has carried out several innovative measures both to diminish the energy consumption and to produce electricity and heat. Active participants in the project were the municipal owned property owners for public profit, and an industrial property owner. Households were engaged in the project through a "communication channel" in which energy data for the apartment were displayed and a few apartments equipped with sensors for lightning, refrigerator, and temperature. The READY project focused on developing new technologies and solutions for demand side response to reduce the energy consumption of households. The technical set-up of the project included: Solar panels which were installed on the rooftops of buildings; Battery energy storage systems for storing excess energy generated by the solar panels; and an interface for energy management at households' level by households. his system was designed to allow for monitoring and controlling the energy use.

2.1.2 Flexiciency

The project was developed by Vattenfall as a large-scale demonstration of technologies for Demand Side Response through active participation of households and by using different app. Around 3000 costumers of Vattenfall were involved in this project. The project focus on developing different apps for two groups of consumers of Vattenfall: costumers who owned heat pump and costumers who owned solar panels The apps had three main functionalities: 1-electricity monitoring; 2- heating and heat steering; 3- real time monitoring and solar electricity production.

2.1.3 InteGrid

InteGrid project was a demonstration of intelligent grid technologies for renewables integration and interactive consumer participation enabling interoperable market solutions and interconnected stakeholders. The Swedish demonstrations were in two districts in Stockholm namely, Stockholm Royal Seaport and Hammarby Sjöstad including in total around 200 apartments. The main focus of these demonstrators was user engagement through devices such as demand side management programs and forecasting signals for the grid side and user signals which were sent through a local social network. The project involved a combination of technical solutions to test how to balance the energy grid. The technical set-up of the project includes PV panels installed on the rooftops of buildings; Battery energy storage systems which were used to store excess energy generated by the PV panels; Electric vehicle charging stations for charging EVs and feeding excess energy back into the grid when needed; smart grid management system for monitoring and controlling the different components of the grid, ensuring that the balance between supply and demand is maintained; and a communication networks for sending signals to the households.

2.1.4 InterFlex

InterFlex (Flexibility in Interaction) was a European project with six demonstration projects in The Netherlands, Germany, Czech Republic, Sweden, and France. The project two Swedish demonstrators in Malmö and Simris village. In this study we investigate the demonstration project in Simris village. The InterFlex demonstration project in Simris was a smart energy grid demonstration project developed by E.ON, a leading energy company in Sweden. The project is focused on demonstrating the technical and economic feasibility of integrating different types of renewable energy sources and energy storage systems into the existing energy grid. The goal of the project is to create a flexible, sustainable and efficient energy system that can handle the integration of renewable energy sources, such as wind and solar power, and energy storage systems. The pilot project has also tested the possibility of integrating renewable energy resources and demand side response devices into local microgrids to achieve islanding capability. The aim of demonstration project in Simris was to test energy technologies and services that could contribute to stability of energy grids that use 100% renewable energy. The demonstration project integrated existing wind turbines and a solar farm with assets that were installed at household's home. These assets were solar panels, batteries, hear pumps and steering devices.

3 Theoretical framework

Material entities such as solar panels, smart meters, monitoring devices, batteries, heating pumps, smart appliance and control devices have a strong presence in smart energy grid's settings. The role of material entities and the agency they develop in enrolling households in smart energy grid projects and shaping the ways users behave in these contexts is also conceptualised in different theories of the close entanglement of social and material dimensions such as the concept of affordance (Gibson, 2014, Schrock, 2015) or Nortje Marres' device-centred perspective on material participation (Marres, 2011, Marres, 2016). We will use these concepts as a backdrop for the empirical framing of the role of such devices by developers.

3.1 Material participation – A device-centred perspective

Marres (2011) defines material participation as the capability of devices (e.g., technologies) and material environments such as smart homes in engaging individuals in societal challenges that go beyond personal reasoning in use of devices. For example, some of the smart home appliances (e.g., dish washers) have a feature to delay the time of use to after the peak energy hours (times of the day that highest amount of energy is used by energy grid's consumers) to reduce the environmental impacts of washing the dishes. In this case, the device i.e., the dish washer enabled the engagement of the households in the action against climate change. In another word the device provided ''the ground for intervention by everyday people'' (Marres, 2011, Marres, 2016) and thus offers a different route to 'political engagement' and the development of an ecological identity. Previous studies investigating material participation in smart energy grids have studied how participation shapes around technologies and device by analysing changes in household behaviour (See for example Throndsen and Ryghaug, 2015, Skjølsvold et al., 2017). In smart energy grids, technologies can be seen as material interventions in co-construction of new and sustainable energy-consuming practices in a shift from energy users to active consumers engaged in the energy system (Ryghaug et al., 2018). A material participation perspective helps to understand household's participation and the role that materials play in their engagement process (Throndsen and Ryghaug, 2015). What we are interested in in this paper is the extent to which technology developers' understanding of household engagement resonates with such concepts of material participation and whether such concepts can contribute to their work. Ideally, such a perspective may help smart grid project developers and technology developers in their design choices and may help planners and policy makers to gain a better understanding of the capability of different kinds of interventions in increasing households' engagement in smart energy grid projects.

3.2 Affordance of technologies in materializing participation

Affordance of an object is in this theoretical setting defined as its ability to change an individual's behaviour (Heft, 1988, Gibson, 2014). In Gibson's concept of affordance, these abilities are a result of (physical) characteristics of the materials (Gibson, 2014). Serval scholars have identified theoretical gaps in Gibson's concept of affordance for investigating the affordance of digital artefacts (Hurley, 2019, Diver, 2018). One example of a gap in Gibson's theory of affordance is its focus on the properties of an object or environment as the sole determinator of how it can be used or interacted with, and its reliance on direct sensory perception. However, this approach falls short when it comes to digital artifacts, which often have multiple layers of affordances, including the user interface, underlying code, and network infrastructure. These layers can be complex and may not be immediately perceivable through the senses. Therefore, Gibson's theory may not fully account for the multifaceted nature of digital affordances (Hurley, 2019, Diver, 2018, Davis and Chouinard, 2016). Heemsbergen (2019) and Schrock (2015) attempted to conceptualize the affordance that digital environments (e.g., social media) and user interfaces create and the way they affect practices. They developed the concept of 'communicative affordance' to explain how digital devices e.g., mobile phones can change practices through affecting the modes of communication and not by perception or reaction of users to the physical characteristics of the device (Schrock, 2015, Heemsbergen, 2019). In the case of smart energy grids, affordance of objects can be seen in the ability of the technologies that are integrated in residential buildings (e.g., feedback mechanism devices) to affect everyday life routines and change energy behaviour. This change of routines is often due to the role of these devices in increasing awareness of consequences of the energy behaviour (e.g., environmental, or financial). It is not only about the physical characteristics of the devices but also how devices help users to understand the connection between their practices and the external consequences of their practices. In case of energy grids such affordance is seen as the ability of technologies to trigger actions upon the perception of consequences of their energy behaviours on the environment.

By studying the role technology affordance has in materialization of participation (Marres, 2011) we tend to analyse the dual relationship between materials and the individuals that use them. The materialization of participation refers to the way that participation, as a social and political process, is enacted and made tangible through material devices. According to Marres (2016), the design and implementation of technologies and platforms play a crucial role in shaping the ways in which individuals and groups are able to participate in various forms of social and political actions, such as engaging in transition towards a low-carbon energy system to address climate change.

Drawing on the concept of affordance and the device centred perspective together for studying the strategies and design choices of the developers allows to investigate (1) developers' perception of the affordance of material environments that are created by feedback mechanism devices in de- and re- composition of everyday material practices of households; and (2) the developers interpretation of how their strategies for mediating with devices through signalling and the (un)changed energy behaviours of the households are connected.

4 Results and discussions

Feedback mechanisms used in smart energy grid pilot projects are the main strategy chosen in the four projects for engaging households. The feedback mechanisms applied, according to the project reports and presentations, are signals (e.g., notifications) that are sent to households who have an active engagement in the projects to inform them about the current energy use and actions that they can take to make their energy use more sustainable. For passive enrolment of the users in the projects, these signals are sent to the steering devices that are installed in their homes for steering their energy consuming devices. For developers load management is a sustainability issues and they believed that steering devices can make a positive impact on the sustainability of household energy use.

Interviewed actors working with households expressed a strong belief that participation of households can preferably be achieved through the design and use of different material devices. This section presents the findings of the study and discusses how project developers and technology designers think about material participation; how they understand households; and how they value and interpret their engagement. The section will describe how project developers' strategies become designed into devices and apps and how these devices shape the actual engagement of households.

4.1 Participation of households in smart energy grid projects

In the four pilot projects, two types of demand responses were tested: technical demand response and behavioural demand response. Behavioural demand response requires active engagement of households but in technical demand response participation is passive and the focus is on user enrolment. The characteristics of these two types of household participation in smart energy grids were extracted from the project reports and are listed in Table 1.

Table 1. Types of household participation in smart energy grid projects

Type of participation	Characteristics of technologies that affect their affordance
Passive enrolment	Agreeing with steering of their devices by project developers
	Allowing access to their data for the feedback mechanism
	Accepting changes applied by project developers in time of use of devices
	Agreeing with terms and conditions of project developers
	Allowing installation of new assets (e.g., solar panels and batteries) in or around the building's envelope
Active engagement	Making manual choices for use of devices
	Reacting to price and environmental signals
	Changing everyday practice for peak shaving
	Installation of assets (e.g., solar panels and batteries) and controlling their performance
	Making own rules and new routines for reduction of energy consumption

The characteristics that were mentioned in the reports point to the importance of material entities such as feedback mechanisms for the participation of households in energy management practices. In this way, we can argue that both passive enrolment and active engagement of households are mediated through devices. In these cases devices are not only facilitating household engagement but they also enable 'a distinctively material form of participation' (Marres, 2011) (p.8).

4.1.1 Engagement mechanism and devices

Deployment of feedback devices was the main strategy that the project developers have chosen for engaging households or enrolling them in the pilot projects. Engagement mechanisms that were designed in these four pilot projects were mainly focused on provision of information and feedback. The devices that were designed for the feedback mechanism includes user interface (e.g., displays, speakers, an apps), smart meters, steering devices, sensors, heating and cooling control systems, and smart appliances. In two pilot projects (READY and FLEXICIENCY) developers designed apps that were able to provide feedback on energy consumption pattern of the users, inform them about how they can make their energy use more sustainable, and to enable them to control their energy-consuming devices through the app. Developers of the InteGrid project chose a display as the main device for user interface. The households were able to follow their energy consumption patterns through these screens, get feedback on their energy use and some recommendations for enhancing the sustainability of their energy consumption pattern. In the InterFlex project the engagement mechanism used technologies such as smart meters, steering devices, sensors and temperature control and adjustment devices for enabling automated decision making to increase the sustainability of energy use of the households involved. The feedback was provided together with the energy bill. According to the project developers of InterFlex, the main strategy for demand side flexibility was developing a feedback mechanism that could send signals between different devices for enabling automated decision making. The direct involvement of households through real-time feedback on their consumption pattern was not part of the developer's strategy for DSF.

4.1.2 Adopting and interacting with material entities

Household engagement in smart energy grid projects is linked to the possibilities for the households to adopt technologies and to interact with them (Latour, 1990). Project developers brought up several factors that can facilitate or create obstacles for technology adoption and interactions with material entities. These factors and examples given by the project developers are listed in Table 2.

Table 2. Factors shaping the adoption and use of engagement devices

Enrolment steps	Influential factors	Description of the factors	Examples given by project developers
Technology adoption	Economic incentives	Subsidies for acquiring devices	Getting a discount for buying solar panels and batteries
	Aesthetic aspects	Integration in interior design and everyday life	The screens installed in the houses for monitoring the energy use and sending signals should fit the interior design of the homes
	Compatibility with existing devices	Lack of any technical and functional conflicts with functionality of other devices	The new devices should not affect households' flexibility in choosing appliances that they use in their houses; they shouldn't have any negative impact on internet speed
	Influence on existing assets	Adding new features to existing assets; increasing the value of house	Possibility of controlling heating and cooling devices through an app
	Laws and regulations	Taxes	Tax reduction on solar panels and batteries
Interaction of households and material entities	Comprehensibility of signals	Easy to understand environmental and price signals	Using easy to understand visualizations such a dying butterfly for signalling unsustainable energy use
	Prioritization of comfort	Prioritizing comfort over cost reduction and environmental sustainability	The temperature of the home will not be changed more than one degree even during peak hours
	Economic incentives	Discount on energy bills	Lower energy prices during off peak hours

	Laws and regulations	GDPR; peer to peer exchange laws	Limitations for exchange of information and comparison functions in mobile phones' applications

4.2 Data, apps, and feedback mechanism

According to an interface developer, apps used in feedback mechanisms facilitate participation by enabling the households to make active choices. The apps can also keep the consumers that their participation is limited through their passive enrolment informed about outcomes of their participation in the project. Apps show how their passive enrolment is resulting in financial or environmental benefits. In the feedback mechanisms, data works as intermediary between developers of energy grids, technologies used in these projects, and the households. According to an interviewee (IIG04) the flow of data has a value chain which involves several actors in the projects.

''there is a whole value chain of how the data goes from smart meters to sort of saving and downloading the data. Initially they are households' data which are owned by them and accessing that data needs their permission. Then data from smart meters goes to the databases of smart meter apps that are usually owned by other companies, then we ask for access to that database, when we have access to the database, then from that database we import the data into Local Life'' (Interview IIG04).

The smart energy grid projects are dependent on households to provide access to the data and agreeing with the terms and conditions of project developers for using the data. ''Data is gathered by devices installed in houses and are transferred to us and we process them. The final product is the signals that we send based on these data in various shapes to the households for making meaningful change in their behaviours.'' (Interview IIF03)

4.3 Feedback mechanisms shaping material engagement

The capacity of feedback mechanism and their environmental and price signals can turn 'everyday material activities into forms of engagement' (Marres, 2011) (p.7). Technologies used in feedback mechanism function as enablers of material participation. In this case, material objects which are used in everyday life of households such as cooking devices, heating devices, or washing machine and everyday material actions such as cooking, heating, or washing are affected by the feedback mechanisms and signals. These signals are supposed to shape a form of engagement with the energy grid and environment (as they show the impact of energy behaviours on environment). In this way material entities adopted by the households and interactions with them enabled household's participation by increasing flexibility from demand side in energy grids which can translate into what Marres defines as 'participation as everyday material action' (Marres, 2011).

Marres (2011) defines materialization of participation the way in which ''material form of participation is actively accomplished with the aid of devices''. In this way, technologies give the 'materiality of participation' a 'performative effect' (Marres, 2011). In the smart energy grid projects signals sent by feedback mechanisms triggered active engagement of households in the projects through its impact on households' energy behaviours. For passive enrolment of households these signals increased the flexibility on the demand side without real-time involvement and decision making of the households. The Simris pilot project tested demand side response without any manual choices. ''The signals weren't sent to the customers. It wasn't an email or notification or anything like this. It was more of a backend connection between systems. It was flow of data between meters installed in each house and the steering devices. We had that direct access to the devices and an automated system for steering the equipment from remote.'' In the Simiris project energy behaviour changing activities were mainly through informing households about the impact they were making and the refunds on the invoices. ''In that way they could feel that they are part of the flexibility or balancing system'' (Interview IIG03).

4.4 De- and re-composition of everyday practices of households in smart energy grids

The project developers believed that feedback mechanism can be used to break down and transform everyday energy consumption practices in households. This process involves two main stages: de-composition and re-composition (Wakeford, 2012, Marres, 2011). During the de-composition stage, materials can disrupt daily life routines, making users aware of the roles, mechanisms, and elements that shape their energy consumption practices. During the re-composition stage, users can change their daily life practices in response to the affordances of materials. For example, smart meters can de-compose cooking practices by sending signals that encourage users to think about electricity flow, time of use, and carbon emissions. By making users more aware of their energy consumption, the smart meter can help re-compose the user's behaviour, making them more conscious of the environmental impact of their actions. An example of the de-composition and re-composition of energy consumption practices can be seen in the pause hours organized in InteGrid's Local Life use case. This approach encourages households to engage in outdoor group activities during peak energy consumption hours, disrupting their regular routines and promoting alternative activities during peak hours that developers believed they are more sustainable practices.

In the Active House use case, the developers expressed that devices and their signals could result in extreme changes in behaviours, even beyond the intended outcomes, such as reducing showering. They considered it as a successful example demonstrated the power of devices in re-composing energy-consuming practices through active participation. In these examples there were two forms of user participation: passive enrolment, which aimed to raise awareness of different behaviour types, and active participation, which involved making changes to daily routines. Passive enrolment aimed to encourage users to engage with climate change by making them aware of the role that their devices play in addressing it, while active participation aimed to change behaviours and engage users more directly with their devices.

The project developers of Actie House aimed to make energy usage more transparent and understandable for households by breaking down complex routines i.e., de-composing their practices. To achieve this, they created a feedback mechanism that demonstrated the internal workings of an energy grid and how it related to daily activities. The goal was to encourage more mindful and sustainable energy usage in households by making energy consumption more visible. Developers considered the feedback mechanisms as an effective tool to help users to become aware of their routines and to recompose their daily practices. Recommendations were sent through communication channels to guide users towards more sustainable practices. The developers aimed to de-compose households' practices by helping them understand how their daily routines and energy are interconnected by understanding energy flow, peak hours, and environmental consequences. To facilitate the re-composition of these practices, the developers engaged households in activities with devices, such as smart meters and thermostats. Signals from these devices were used to encourage changes in behaviours, increasing demand-side flexibility.

In the InterFlex project, re-composition was based on setting sustainability goals at three levels: individuals, building, and community. By joining efforts to reach a collective goal, households were motivated to reduce their energy consumption and change their behaviour. For instance, in the Active House project, this led to changes in living standards, such as adjusting the thermostat and using more energy-efficient appliances. The feedback mechanism played a crucial role in this process, as it helped households to understand how their energy consumption related to their sustainability goals. To sign up for these goals, households were informed about the project and its objectives. However, not all households were aware of the goals or how to achieve them. Devices such as smart meters and signalling devices (i.e., a screen for visualization of the data on energy use) were used to provide feedback and guidance to households, and the project managers also provided educational resources and training sessions to help households understand how to reduce their energy consumption.

In the Local Life project, some households were able to reduce their electricity consumption by 20%, and some even stopped using hot water in their tubs. Although the project manager was unsure of how some households managed to shower without hot water, this reduction in energy consumption can be attributed to the setting of collective sustainability goals (Interview IIF03). By setting these goals, households were motivated to reduce their energy consumption and adopt new practices. Developers explained that the feedback mechanism also helped to create new practices for peak load reduction. The app used in the Local Life project provided opportunities for tenants to participate in low-energy-consuming group activities during peak hours, such as walking in nature, running, and having coffee with others. By doing so, tenants were able to reduce their energy consumption during peak hours, and the project developers reported a 4% peak load reduction. The Local Life project demonstrated that changing behaviours does not always require high-tech solutions and that collective sustainability goals can be achieved through low-energy-consuming group activities (Interview IIF03).

Studies that applied material participation for analysing households' behaviours and the potentials of engaging them in smart energy grids also touch upon the interrelations between technologies and consumers and looked at the role of technologies such as smart meters in de-composition of everyday routines. A study done by Throndsen and Ryghaug (2015) on household's participation in a pilot project in Norway, which was based on focus group interviews, suggests that smart meters allowed users to see the energy and to look for political motives behind these projects. Their study showed that households' engagement or disengagement in smart energy grids is a result of the potential of devices (i.e., smart meters) to display the relationship between their participation, socioeconomic benefits and ''green political economy aspects such as the climate challenge'' (Throndsen and Ryghaug, 2015)(p. 163).

4.5 Minimization of invested effort for increasing the doability of material participation

According to the project developers only projects can be successful that give the households the feeling that they are making an impact without doing anything complicated or without making big changes in their everyday life. The Simris project was initiated with the ideology to make the participation of households in a more sustainable electricity system easy by using material devices to facilitate engagement. Their approach for making household's participation easy was by delegating much of the engagement work to material devices. One of Simris project developers stated that ''costumers would participate [in the pilot projects] if they are not obliged to [actively] participate'' (IIG02). This quote shows how they take one step further in minimization of invested effort by focusing on passive enrolment of households and interpreting that as user's participation. Minimization of effort also includes making participation doable and attractive. From developers point of views, attractiveness of participation is in the financial incentives that are offered to households to participate and to de- and re-compose their energy behaviours. Project developers pointed to financial incentives as a key for household's involvement in the projects, changing their energy behaviours and to avoid conflicts and legal issues. In Simris, households' participation was only possible with discounts on materials and devices that needed to be installed in each house. The project developers mentioned that not only offering the devices with a lower price was important but also the impact that these materials had on the value of the houses. ''the devices provide direct values to the customers and what we did was offering these customers quite a lot of money to participate. So, we did a survey to see what the motivations are to participate in this project. Even if a lot of customers said things like we would like to participate in this project because of environmental reasons but in practice what really motivated them was the financial incentives. So, for the new heat pumps and for the new solar systems we offered them a 50% discount on these devices. In some cases, we paid up to 100.000 Swedish kronor in discounts. Because we needed the devices to participate than to see what would happen.'' (Interview IIP03). According to a project manager of Simris, the incentives had a role in decreasing the complaints from the households about the changes households' everyday life routines that were caused by their interventions.

Project developers and designers of user interfaces argued that incentives for acquiring new devices and the signals that could help households to reduce their energy costs are the drivers of households participate in energy grids. However, their view of household's participation and what re-compose their behaviours is in contrast with the findings of Throndsen and Ryghaug (2015) who studied households and their behaviours. They showed that reducing households to consumers instead of partners in developing a common project and for reaching a common sustainability goal can result in their disengagement in smart energy grids. They concluded that focusing on economic incentives for enabling participation is in contrast with making individual's energy behaviours and domestic use public (Throndsen and Ryghaug, 2015).

For making the participation doable, the signals should be easily understandable and possible reactions to signals should be simple and easy. Project managers in all projects mentioned that the main challenge in households' engagements was the fact that smart energy feedback mechanisms are ''engineered driven''. They are developed by engineers and for people who are keen to spend a lot of time in exploring them. ''they do it with the idea that everybody will change and be super-excited. And that is true for a very small percentage of the people.''

(Interview IIG01). According to an interviewee (IIF01) the attention span of households to new things is very limited. Therefore, engagement of them is only possible with value creations which make their life more comfortable and enjoyable for example by providing the possibility for them to use their washing machine for doing laundry before they get home. Another interviewee described an active customer as someone responding to any kind of signal and making manual choices. Such an active engagement and making manual choices can be slow. ''What we need for a smart energy grid is to be fast, so I don't think making manual choices is a perfect solution'' (IIF03). The automatization of decision making in material participation shift the focus from devices enabling operation by households to the interactions among material entities.

To make material participation doable it must be made easy (Marres, 2011). In smart energy grids, minimisation of invested effort can be defined as reduction of expectation from households (Marres, 2016). To make the participation easy, the project developers have chosen different strategies. For example, in Ready project the feedback on households' energy behaviours were visualized as butterflies. A flying butterfly indicates sustainable energy behaviours and a dying butterfly represent high energy consumptions. The developers of the Interface of Life said that ''we make it accessible in smart phones, tablets, computers, even on TV screen. To make it easy for the tenant to connect and react'' (Interview IRE01). The importance of doability for households participation in smart energy grids in in line with Marres (2011) statement on public participation which argues that participation ''must somehow be made 'doable' for everyday people - who lack the time, space and shared knowledge''. (P.9) The strategy of developers of smart energy grids has been moving towards a "passive" engagement approach, which seeks to make participation in energy-saving practices as easy and unobtrusive as possible for end-users. This approach is seen as a way to reduce the "problem" of user resistance to changing their daily routines and habits, which has often been identified as a major barrier to successful implementation of smart energy technologies. However, this strategy seems to run counter to the perspectives put forward by scholars such as Marres (2016) and Throndsen and Ryghaug (2015), who argue for the importance of active participation which also regards time, space, and effort in order to achieve meaningful and lasting changes in energy consumption practices (Throndsen and Ryghaug, 2015). While developers may see passive engagement as a way to make participation less problematic for end-users, Marres (2016) suggests that success of such project is dependent on the way in which they actively shape the material environment to make new behaviours more convenient, or finding ways to make participation more enjoyable and rewarding. However, both perspectives have their strengths and limitations. Passive engagement may be more effective in certain contexts or for certain groups of users, while active participation may be more appropriate in others. Ultimately, the key is to find the right balance between these two approaches and to tailor energy-saving interventions to the specific needs and preferences of end-users. By taking a more nuanced and context-specific approach, developers can better understand how to motivate people to make sustainable changes in the energy consumption practices of households.

4.6 Interdependency among material entities in materialization of participation

Marres (2016) argues that materialisation is often afforded by devices and the operations that they enable (Marres, 2016). But material entities or devices need to gain agency to provide such an affordance (Latour, 2005). Material entities gain this agency through their connection and interaction with other social and material entities (Callon, 1987). In smart energy grid projects, households' participation is de-composed and re-composed by signals. But existence of these signals is dependent on interactions among other material entities such as smart meters, apps, laws and regulations, data, internet connection, etc. In the Simris project, several households were excluded from the project because of lack of internet connection. The aesthetic aspects of devices that were used for display of signals in Active House brought about many complaints about their unfitness to interior design of the houses.

Household's participation is constituted by material performances. Material participation, especially through smart meters and steering devices, are the act of participation and enable households' engagement. In these cases, devices (materials) become object of households' performance. Once households are enrolled in smart energy grid projects, they adopted new technologies and interact with them, agency of the material entities can change households' energy behaviours. The agency of material entitles in changing households' energy behaviours is dependent on their visibility and interactivity. A project developer stated that material entities that are invisible to households and don't communicate with them may influence the amount energy that is used by households, but they can't change their behaviours. Material entities that become part of households' everyday life and are visible to them or communicate with the households through screens, online platforms or applications have the capacity to change households' energy behaviours. The agency of visible material entities in changing households' energy behaviours is affected by the aesthetic aspects of the materials and their compatibility with the existing assets. The agency of interactive material entities is also dependent on understandability of the signals that they send (texts, images, graphs, etc.) for the households.

The apps are one of the main tools for transferring the signals to the households therefore an important device in the feedback mechanism for materialization of household's participation. An investigation done within the FLEXICIENCY project showed ''that some of the participants were really going in the app and checking on their production and stayed engaged. They didn't want only solar panels; they also wanted this kind of engagement'' (Interview IFL019). The app used in the READY project, Interface of Life, was the only communication channel between households and project developers. By using the app households were connected to their homes and home appliances. However, some functions of the apps for example control of home appliances and temperature with the phone can also have undesired results and increase the energy consumption. The interactions between material entities and households can take a different shape than what has been intended by the developers. In FLEXICIENCY project the app that was designed for sending environmental and price signals and adjusting the energy consumption by for example reducing the temperature has led to increasing energy consumption by the households. The investigations done by Vattenfall showed that easy access to the heat steering through phones and prioritisation of comfort over the price of electricity have changed the use of the app by the households. A project manager of FLEXICIENCY argued that only increasing economic incentives which would make the difference in the energy costs more notable could change households' energy behaviours.

The interactions between the feedback mechanisms and the apps are configured by the context. Although the apps were also able to limit the use of energy by home appliances during peak hours by scheduling for example the dishwasher outside peak hours. But it didn't become a popular feature because of the ''flat rate for the tenants. So, they have the same price for the whole year and the whole day. That is the problem.'' (Interview IRE01). The use of app and their features can also be affected by laws such as privacy law (i.e., GDPR) which limits many functions such as comparing energy behaviours among neighbours.

Technology developers believed that to re-compose daily routines and energy consumption behaviours devices need to interact with households in real-time. To gain the capacity to signal in real-time the feedback mechanisms are relied on many social and material entities that are involved in the process of registering households' energy behaviour through smart meters, collecting the data, processing them, and sending signals to households. For example, the signals were less effective in Local Life because they had one day delay. ''Feedbacks must be real-time, we had one day delay and it didn't mean anything to users they wanted to see what they immediate action mean. In one day, they forget about it and don't think about their energy behaviour yesterday'' (Interview IIG04). Trust is another of the characteristics that developers believe that material should gain to be able to afford operation for material participation. ''We need households to trust technologies and services that we are providing. Then technologies can enable the devices to function based on default choices that households agreed with them'' (IIF03). Technology developers believe that in the projects where households have a passive role, technologies can function as an intermediary for actively making households participate in the projects without making any manual choices, by gaining household's trust.

Project developers stated that both active engagement and passive enrolment of households in these projects are linked to services that they provided using households' data. In passive enrolment of household, data's interactions with automation and steering devices are a key to success of demand side response. In FLEXICIENCY project households' involvement was mainly though providing data. ''households were providing the data and apart from that they had to agree with access and use of data by us for the service that we build and provide based on these data, so they could somehow engage, and they could have a role on the system behaviours.'' (Interview IFL01). In active engagement households' understanding of visualized data affects their 'manual choices' for changing their energy behaviours and consumption patterns. The access to these data were also a key to development of smart energy grids and active engagement of the households. Accessing data allowed companies such as Vattenfall to provide services to their clients by providing ''more information about their energy behaviour by going to an app, and this is only possible because Vattenfall in its standardized manner have access to the data and is able to develop this type of app. In this way households were able to have a more interactive role and interesting interface to become engaged. These data were used to build load prognoses, alerts and send them tips and tricks based on the behaviours for reducing their energy consumption and making their energy behaviours more sustainable.'' (Interview IFL01).

The interactions between material entities can also involve new social entities in the projects. The data that is used for feedback mechanism are owned by energy providers. When the app that is used for sending signals, extracts these data from smart meters the energy providers, which are not an official partner in the project, become an involved actor in the project. Their involvement has caused several legal issues in the four pilot projects because the extraction of data from meters are seen as a service which can result in additional costs of consumer's bill.

The increase in energy bills of households has forced developers of InteGrid to change their strategy for providing signals.

5 Conclusion

Affordance of technologies in changing energy behaviours of the households, re-composing households' energy-consuming practices in a way that environmental consequences are taken into consideration, requires technologies with certain characteristic. These characteristics, based on the findings of this study, are: real-time interaction with users for active engagement and gaining user's trust; compatibility with other assets and devices in terms of function and aesthetic aspects; doability; attractiveness to enrol by offering economic benefits; additional added value offered by devices such as increasing user's control in using other appliance from distance; visibility of devices; clarity of the signals that they sent for communication with users; and ease of use. This can be complemented by findings of Skjølsvold et al. (2017) who looked at how households interpreted and understood the technology, and how the technology re-composed their daily routines. They argue that although affordance of technologies can open up for new practices by making energy consumption of devices visible, for a transformative change mutual relationship between the technologies and users is required. This relationship should not be limited to price signals for reducing the energy costs of users, but to help engaged consumers to understand social and environmental impact of their participation (Skjølsvold et al., 2017).

The findings of the paper showed that the technology and project developers believed that creation of household engagements (for both active participation and passive enrolment) is mainly influenced by the (communicative) affordance of technologies and interfaces (i.e., mobile app) in taking over some responsibilities from households (to minimize the required effort). This potential of technologies is understood as a solution for optimizing the energy behaviours of households in a way that it would have both environmental and financial benefits. Their understanding of affordance of technologies in material participation and engagement creation was based on their view of potential of technologies in performing everyday practices of households instead of them. This shapes a different type of material participation than what Marres (2016) explains. She saw material participation in the ability of technologies in engaging people with environmental issues. But the way developers understand engagement creation is mainly related to how people accept technologies to solve environmental issues without their direct engagement with such challenges. If we compare these findings which are based on developers' view of engagement with findings of Skjølsvold et al. (2017) and Throndsen and Ryghaug (2015) which were based on the households' perception we can see that developers' view (at least in these cases) of household's desire to be actively engaged with societal issues and their interest in becoming eco-conscious energy consumers was very limited (Gao and Souza, 2022).

The paper studied the understanding of technology developers of four smart energy pilot project in Sweden of household engagement creation through technologies that they have designed or applied in these projects. The paper also investigated how developers understanding of materialization of participation has affected their design choices. The findings showed that developers are aware that the technologies should not be designed for experts as they should be easy to use for households without any previous experience or in many cases lack of interest in technologies. However, based on the results, developers instead of changing the design of devices in a way that they would facilitate engagement of households, they have chosen a different strategy. Instead of relying on affordance of technologies in change of energy-consuming behaviours, they developed technologies that engage devices, i.e., houses and appliances that are used in the houses, in resolving societal issues without direct involvement of households or giving control over everyday technologies. The focus was on engineering trust in technologies used in smart energy grids to deal with environmental issue without the need for households' active participation. However, comparing this result with studies that investigated households' perception of material participation shows that such a view of engagement creation is a result of limited view of developers of energy consumers and their motivations.

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7 Appendix:

Table S1. List of interviewees

Code	Affiliation	Project	Location	Date
IRE01	Wexnet	READY	Zoom	6 October 2020
IRE02	Växjö Energy AB	READY	Municipality of Växjö	8 September 2020
IRE03	Växjöbostäder	READY	Phone call	16 October 2020
IRE04	Växjöbostäder	READY	Phone call	29 March 2021
IRE05	Akatingo	READY	Phone call	30 September 2020
IIG01	E-REDES	InteGrid	Teams	10 September 2020
IIG02	KTH	InteGrid	Zoom	23 October 2020
IIG03	KTH	InteGrid	Zoom	10 November 2020
IIG04	KTH	InteGrid	Zoom	6 November 2020
IFL01	Vattenfall	FLEXICIENCY	Teams	2 September 2020
IIF01	EON/Novion	InterFlex	Teams	4 September 2020
IIF02	EON	InterFlex	Teams	22 April 2021
IIF03	EON	InterFlex	Zoom	11 February 2021

Table S2. List of project reports and presentations

Code	Type of document	Project	Tile	Author	Submission date
RREO 1	Report	READY	Final publishable summary report	Reto M. Hummelshøj	Nov. 2020
RREO 2	Report	READY	Evaluation of the operational monitoring data of the demonstration projects	TN (AIT) + EMZI	09.02.2021
RREO 3	Report	READY	Behavioural campaign for energy efficiency and smart living solutions module & report	Krushna Mahapatra	30 June 2020
RREO 4	Report	READY	Report on energy performance of the project in close collaboration with WP7	Sofie Nielsen	25th April 2017
RREO 5	Official project presentati on	READY	Digital transition for smart living	Sara Eliasson	16 Oct 2020
RREO 6	Presentati on	READY	Interface of Life	Per Bengtsson	
RIF01	Report	InterFle x	Investigation and comparison of EU-wide regulations and rules concerning the commercialization of endcustomers flexibility and building local energy market places/platforms	Marco Cupelli, Milica Bogdanovic, Thomas Schütz	June 30th 2017
RIF02	Report	InterFle x	Raw demonstration results based on the KPI measurements	Helen Carlström, Karolina Ekerlund, Sebastian Jansson, Jörgen Rosvall	30/06/2019
RIF03	Report	InterFle x	Innovative solutions to be tested in the demos	Peder Kjellén, Thomas Fischer, Alexandre Blondot, Luiz Hernandez	29/06/2018
RIF04	Report	InterFle x	Lessons learnt to draw business models in use case SE#5	Fabian Regier, Jörgen Rosvall, Hendrik Flamme, Gonca Gürses-Tran Pauline Ahlgren, Fabian Regier	30/06/2019

RIF05	Report	InterFlex	Local energy system in Simris. Can a village become self-supporting on electricity?	PFM research and EON	18-02-2020
RIF06	Report	InterFlex	2 Lessons learnt to draw business models in use case #4	Jörgen Rosvall, Sebastian Jansson	31-10-2019
RIF07	Official project presentation	InterFlex	Simris	Jörgen Rosvall	
RIG01	Report	InteGrid	Consumer's Engagement Strategies	Carmen Escudero Guirado, Victoria Labajo, Carmen Valor, Paula Bögel, Annika Giersiepen, Carolina Koronen, Aram Mäkivierikko, Anders Nilsson, Hossein Shahrokni	30.06.2018
RIG02	Report	InteGrid	Business Models to Support the Developed Concepts	Rafael Cossent, Leandro Lind, Lorenzo Simons, Pablo Frías, Carmen Valor, Mauricio Correa	07.07.2020
RIG03	Report	InteGrid	Stakeholder Consultation	Rafael Cossent, Leandro Lind, Carmen Valor, Victoria Labajo, Carmen Escudero	06.07.2020
RIG04	Report	Integrid	Technical Scalability and Replicability of the InteGrid smart grid functionalities	Julien Le Baut	03.01.2019
RIG05	Report	Integrid	Economic and regulatory scalability and replicability of the InteGrid smart grid functionalities	Rafael Cossent, Leandro Lind, Mauricio Correa, Tomás Gómez	21.02.2020
RIG06	Official project presentation	Integrid	Active House and Local Life used cases	Hossein Shahrokhi	
RFL01	Report	FLEXICIENCY	Final report on the progress of work and use of resources	Marco Baron and WP leaders	1/04/2019

RFL02	Report	FLEXICIENCY	Cross-case analysis of the results from the demonstrations	VaasaETT, Circe, E-Distribuzione, ENEL Energia, Joule Assets, Siemens, University of Ljubljana, Vattenfall, Verbund	20-07-2019
RFL03	Report	FLEXICIENCY	Results achieved in the Swedish demonstration	Christina Svalstedt, Marie Nylin, Ying Pang	31-12-2018
RFL04	Official project presentation	FLEXICIENCY	FLEXICIENCY	Fanny Lindberg	