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# Household energy resilience: Shifting perspectives to reveal opportunities for renewable energy futures in affluent contexts

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ABSTRACT

Energy resilience is an important focus for energy policy and research, since the energy system is increasingly facing challenges such as power shortages, e.g. due to increased renewable energy production, and risks of power outages caused by extreme weathers. Typically, energy resilience in these contexts focuses on infrastructure and securing supply of electricity despite disturbances. This paper contributes a complementary perspective on resilience, which takes households as a starting point for investigating resilience. Building on understandings of resilience from several disciplines, we suggest a definition of household energy resilience that can be used to explore how households can ensure a good life in a future with variable availability of electricity. Furthermore, we draw on current ideas of future domestic energy use in energy affluent contexts (backup energy sources, energy efficiency, flexibility, and energy sufficiency) to create a framework for exploring household energy resilience. We find a potential for diversity within and between the different ideas, that is not always present in mainstream visions of future energy use. With the perspective of household energy resilience, we wish to challenge the perception of electricity demand as non-negotiable and to reveal opportunities for supporting households in becoming more resilient in an uncertain future.

## 1. Introduction

In order to meet the United Nations' Sustainable Development Goals and to address climate change in line with the Paris Agreement, transitioning to renewable energy production is urgently needed. It is estimated that the share of renewables in global power generation needs to be 85% by 2050, and provide about two thirds of the total energy production, to meet these goals [1]. However, even though renewable energy production promises to phase out fossil fuels, it presents new challenges to society. Specifically, fossil fuels are controllable in a way that most renewable energy sources are not – you can burn more coal, but you cannot get the sun to shine brighter. Intermittent electricity production, in combination with (local) limitations in grid capacity, means that there is a greater risk of power shortage when peaks in electricity demand clash with low production of renewable energy. Power shortages today may require load shedding, where electricity supply is cut off to some customers, but could in the future also include more refined ways of limiting electricity use to prioritised appliances and systems [2,3].

Much research, industry and policy effort are put into investigating how power shortages and load shedding can be *avoided* by involving households in load balancing. Supply and demand can be balanced, for example through energy storage [4], time-of-use pricing [5] and automated operation of electricity-intensive appliances [6], with the goal of preventing disruptions for customers. However, less work has been put into understanding if and how some disruptions could become *acceptable* in the future, which is the focus of this paper. If households can be supported in adapting to some types of disruptions, this could be an acceptable complement to other forms of grid management. Lower requirements on reliable electricity supply reduce the need for grid expansion, which could reduce costs for customers [7] and may speed up a transition to renewable energy.

Another reason for investigating how disruptions in power supply can be managed by households, is that more frequent extreme weather events, caused by climate change, increase the risk of power outages [8]. At the same time, global electricity use is expected to increase with about 50% by 2040 due to increased access to electricity and electrification of sectors currently relying on other sources of energy [2]. Digitalisation further increases our reliance on electricity to power the data centres, networks and devices that allow for digital communication,

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smart homes systems, electronic payments and much more. Consequently, the world is becoming more dependent on stable access to electricity at the same time as the risk of power shortages and power outages is increasing.

In many parts of the world, unstable access to electricity is a reality today. This has a significant impact on households' everyday practices [9] and may also cause problems at a societal level when some citizens have more stable access to electricity than others [10]. In contrast, from a household perspective of *energy affluent contexts*, electricity access and use are often taken for granted as an evident right, as means to carry out everyday practices and satisfy needs of comfort and convenience [11–13]. We are not suggesting that the energy reality in many resource-limited contexts today is an energy future to strive for, but we see an underexplored space between severe disruptions that significantly restrain everyday life and an everyday life with extremely reliable access to electricity. It is unclear how affluent households who are used to constant access to electricity would be affected by and deal with an increased variability in availability of electricity, and if or how this could be considered a good life. However, it is clear that a future with more disruptions is in conflict with the increasing reliance on electricity that we see across many parts of society today.

In this conceptual paper, we suggest a new perspective on households' roles in a renewable energy future, where we question the narrative of power shortages and power cuts as unacceptable events to avoid at any cost. Instead, we develop a perspective of *household energy resilience* to focus on possibilities for households that currently are used to stable access to electricity to live a good life despite variable availability of electricity. Our objectives are to:

- Provide a definition of household energy resilience that reflects an alternative role for households in a renewable energy future.
- Create a framework for household energy resilience that can support explorations of household energy resilience, and that draws on current ideas of future domestic electricity use in affluent contexts.
- Highlight potential challenges and opportunities when applying such a framework to empirical studies or in practice.

In Section 2, we describe the scope and research approach for how we addressed these objectives. In Section 3, we define household energy resilience in relation to different understandings of resilience and we use this definition in Section 4 to develop the framework for household energy resilience. Finally, in Section 5, we discuss the framework and considerations when applying it.

## 2. Scope and research approach

In energy forecasts and scenarios for the EU [14], the UK [15] and Australia [7], disruptions in electricity supply are treated as *risks*, that need to be mitigated through various means of load balancing, rather than as *opportunities* for load balancing. However, in a scenario from the Swedish Energy Agency [3], describing a future Swedish energy system in line with the Paris agreement and reaching the 1.5 °C goal, disruptions are a small part of a strategy for an almost fully renewable energy system. The scenario is called 'Legato' and, in addition to solutions such as centralised energy storage and highly flexible electricity users, the scenario briefly mentions that users, either voluntarily or through formal agreements, accept to occasionally be *disconnected from the grid* or have *a cap on power use* for a few hours. From the scenario we do not, however, get any idea of how disruptions can be made acceptable to households that today are used to constant access to electricity or what this would mean for them. This is similar to other future energy scenarios that focus on technology but where people's everyday lives are largely absent [16].

Therefore, we used the two types of disruptions from the Legato scenario as a basis for creating a framework that can be used to explore specifically what a scenario with disconnection from the grid (which we will refer to as *power outages*) and a cap on power use (which we will refer to as *power shortages* at a household level) might mean for households. These disruptions in electricity provision were combined with different perspectives on resilience from literature related to domestic energy use to create a definition of household energy resilience. Although the scenario we drew from is created for Sweden, the disruptions in power supply are combined with more common solutions that are included in other energy scenarios for affluent contexts (e.g. [7,14,15]), such as energy storage, flexible energy users and smart technology. We therefore believe that this is relevant also for other affluent contexts.

The framework for household energy resilience was created from the components of the definition of household energy resilience together with a narrative review [17] taking four different ideas of future domestic energy use as a starting point: (1) using *backup energy sources* to provide electricity or energy in other forms that support household practices, (2) increasing the *energy efficiency* of electrical appliances to reduce overall energy demand or the power needed for a specific activity, (3) applying *flexibility* in terms of adapting electricity use to the current supply, and (4) applying principles of *energy sufficiency* to reduce energy demand temporarily or in the long term. We chose the first three ideas because they are already discussed in scenarios for (affluent) households' roles in future electricity systems (e.g. [3,7,14,15]) and, despite mostly not concerned with household experiences of power outages and shortages, the core principles of the ideas can also be used to different extents in scenarios with disruptions. The fourth idea, sufficiency, is an emerging concept within domestic energy use which is directly related to 'doing without' [18] and we therefore found it interesting from a perspective of disruptions in electricity supply.

Inductively, from examples in literature on domestic energy use, and deductively, we created subthemes for each of the four ideas based on what means for resilience they provide, for example 'human power' as a subtheme of 'backup energy sources'. We then searched for literature related to each means for resilience, for example articles published in this journal and in Energy Policy, and energy related research from the field of human-computer interaction. Aspects we analysed in the literature and used for the framework included: relevance for different types of disturbances; implications for households regarding possibilities of living a good life; and societal and environmental consequences to consider when exploring household energy resilience. This was an iterative process where we searched for additional literature, for example using backward snowballing [19], when we found interesting aspects relating to resilience as well as when we identified new means for resilience in the literature. With this narrative review, our aim was never to achieve a complete overview of relevant literature, but to explore the diversity and the possibilities of existing examples in literature.

## 3. Household energy resilience

The concept of resilience is explored in numerous disciplines with different interpretations (see e.g. [20] for an overview). It is beyond the scope of this paper to report all perspectives here. Instead, we are building on existing resilience literature in areas related to domestic energy use to develop an understanding and definition of household energy resilience. Hamborg and colleagues [21] developed a resilience framework for electricity systems in which resilience is described as an *entity* with a *function* where resilience is the persistence or fulfilment of the function in the face of *disturbances*. In much energy related resilience research, the energy system or power system is taken as the resilience entity and energy supply is the function to sustain (e.g. [22–24]). The focus on a resilient energy infrastructure and securing uninterrupted supply is also central in energy policy [25,26]. However, similarly as in development studies (e.g. [27,28]) and household preparedness (e.g. [29–31]), we here regard the *household* as the resilience entity. The perspective of the household as the entity is meaningful for our work towards a renewable energy future as it reveals possibilities to cope with energy-related disturbances in ways that are not dependent on electricity (e.g., cycling when an electric car cannot be charged), and highlights different households' varying preconditions, such as possibilities to have solar panels or not.

While we take the household as the entity in our definition, households should not be seen as isolated from wider issues in society, or not interacting with each other. Instead, we see a household as a site where different societal sectors and systems become integrated through everyday life and where the impact from changes within sectors and systems become visible, including the interaction between these at a household level. Households are further impacted both by existing policies and the possible pathways for change they open for [32]. As stressed increasingly in the literature, resilience needs to be understood as a change process taking place across horizontal and vertical scales in society [33]. Similarly, the concept of 'panarchy' describes how systems develop and interact through nested series of adaptive cycles (see e.g., [34] for an overview). With inspiration from looking across scales and from the panarchy concept, we take households as a starting point to make visible ways to develop resilience *together*, both within and beyond households.

Seeing the household as the entity (while recognising households' interconnectedness), we suggest *living a good life*, rather than constant access to electricity, as the function to be fulfilled in the face of disturbances. We see 'a good life' as something that is subjectively and dynamically defined in relation to the socio-cultural and economical context. Taking a good life as the function shares similarities with socio-ecological resilience in which "continue to support human well-being" can be interpreted as the function [35]:2. Everyday life is central also in Abi Ghanem and colleagues' study of how households can manage day-to-day life during power outages [36] and in Heidenstrøm's study of 'informal household preparedness' [29]. However, these studies focus on low-probability and high-impact disturbances, such as blackouts, that can be considered *crises* happening in everyday life. In household energy resilience, we instead focus on a new normal where also more frequent, but less severe, energy-related disturbances could become part of our everyday life.

Fulfilling a function does not mean to keep on functioning in the same way. The resilience literature provides different conceptualisations of what constitutes resilient system behaviour in terms of function fulfilment (see overview in [37]). Here, we use a conceptualisation by Hamborg and colleagues [21] as it includes analytically distinct and established resilient behaviours (see similarities with conceptualisations in e.g., [27,38,39]), it separates between system behaviours before and after a disturbance, and it was found to fit with 'a good life' as the function to fulfil. The four resilient behaviours are: *toleration*, *restoration*, *adaptation*, and *transformation*. Toleration, to absorb the disturbance without affecting function fulfilment, and restoration, to restore the function after the disturbance, i.e., to 'bounce back', are both *absorptive* system behaviours that occur *during or after* a disturbance [21]. Adaptation, to prepare for a disturbance so that the system's tolerance or restorability is enhanced, and transformation, to 'fundamentally change' the system [40] and completely bypass disturbances, are both *preventive* behaviours occurring *before* a disturbance [21].

It is important to highlight the differences between adaptations that are more limited and occur within the current system and potentially reinforce an unsustainable system [33], and transformations in which disturbances becomes the reason for changes towards a more sustainable future [34], sometimes referred to as 'bouncing forward' [41]. However, in line with [42], we acknowledge that the term 'bouncing forward' could be understood as assuming that there is a new equilibrium to reach, which there might not be as the ongoing climate changes will constantly pose new challenges. Transformations are by some scholars described at a household level [38,43], while others include higher levels, such as communities and government [33,39]. Irrespective of position, we recognize that transformations in society will affect households in a way that, from the perspective of the household, is perceived as fundamental changes. In fact, we believe that the ability to change fundamentally is an important aspect in household energy resilience – both because people's needs and understandings of a good life change over time, and because of the urgent need to transition to a low-carbon society, specifically for affluent households [44].

Abi Ghanem and colleagues provide a definition of energy resilience in households that suggests how *toleration*, *restoration*, *adaptation*, and *transformation* can be performed in the context of everyday life: "Resilience can be defined and understood as modifying the performance of practices through changing material elements, gaining knowledge for how 'to do' things during a power cut, and accepting new meanings for achieving comfort, convenience and cleanliness" [36]:178. In this understanding, changing the performance of everyday life is central, and these changes include material elements, knowledge, and the acceptance of new meanings. Furthermore, in the understanding of informal household preparedness, preparedness can be seen as "[ …] interwoven in many of the practices that households perform" [45]:274 and it is "[…] not performed in itself but follows the structures of the integrative practice of which it is part" [46]:3. We believe this focus on integration of preparedness into already existing practices is constructive also for understanding and increasing household energy resilience.

Based on the household as the entity and a good life as the entity's function, which should be fulfilled despite disturbances in a renewable energy future, we have developed the following definition of household energy resilience (see also Fig. 1):

*As an interwoven part of everyday life, household energy resilience is to ensure a good life through adjusting what activities that are performed, when they are performed and how they are performed in the face of expected and unexpected power outages and shortages as well as to prepare for future adjustments of activities and to more fundamentally change to reduce the need for adjustments.*

Drawing further on the work of Abi Ghanem and colleagues [37], ideas of iteratively learning from previous experiences [38,47,48], and on resilience as constant changes [42], we find it useful to make the following clarifications:

To be able to adjust activities, households need to have knowledge about and experience of how adjustments can be made, have possibilities to make these adjustments, and accept or create new meanings of what a good life is. Adjusting how activities are performed includes modifications of what products, systems and resources are used for the activity, how they are interacted with, and what the result of the activity is. To prepare for future adjustments and to more fundamentally change to reduce the need for adjustments, households can iteratively learn how to adjust or to do without, experiment with new meanings, and/or get access to suitable products, systems, and resources. Preparations and changes will be ongoing processes as experiences and conditions evolve. Finally, adjustments and changes depend on and will be affected by factors also beyond the household and will require changes in, for example, infrastructure and policy as well.

We argue that a household perspective on energy resilience can be a constructive complement to the currently dominating focus on energy supply and infrastructure in resilience literature and policy, as well as a way of questioning the perception of electricity demand as non-negotiable. Focusing on ways of living 'a good life' despite variable availability of electricity, rather than securing energy supply, opens for new and complementary ways of achieving overall energy system resilience. As of yet, household energy resilience in a renewable energy future is largely unexplored, both as a perspective and in terms of practical examples and experiments. In this paper, we use the definition of household energy resilience to build a framework for exploring how households can be supported in living a good life despite power outages and shortages and what such a future may look like.

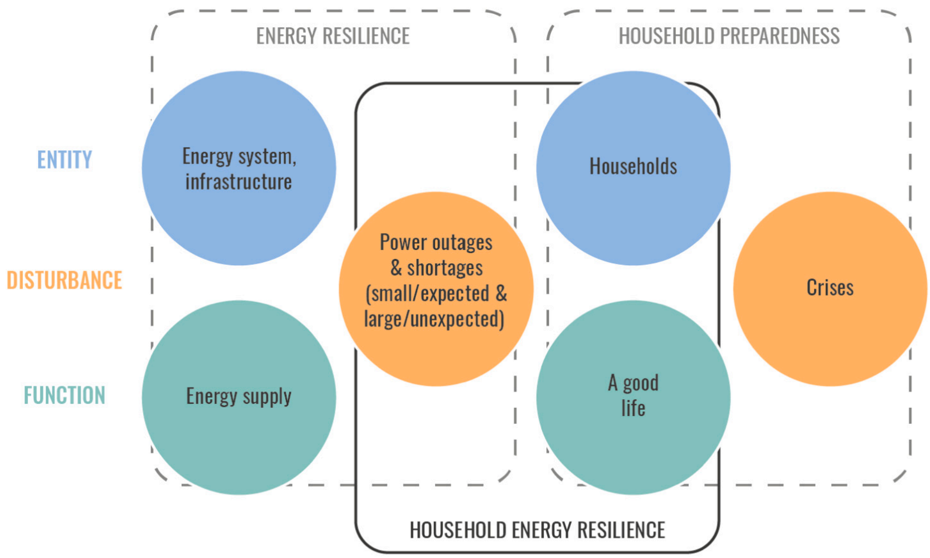


**Fig. 1.** Household energy resilience draws on both energy resilience and household preparedness. As in household preparedness, household energy resilience takes households as its entity and a good life is the function to be fulfilled. But, while household preparedness focuses on events that can be considered crises in everyday life, household energy resilience addresses a wider range of disturbances, from small to large and expected as well as unexpected. Both power outages and shortages are considered, just as in energy resilience.

## 4. Domestic energy use and household energy resilience

There is already plenty of research and practical examples that are relevant for supporting an understanding of what household energy resilience could mean in practice. To develop a framework for household energy resilience, we have explored literature related to domestic energy use in various contexts with a focus on four current ideas connected to future energy use: backup energy sources, energy efficiency, flexibility, and energy sufficiency.

These ideas imply very different scenarios for changes in household electricity use – ranging from potentially no noticeable change for households to imagining radical changes in electricity-dependent practices. To form the framework, we have analysed examples and insights from the literature with regards to what means for developing resilience they might provide, what types of disturbances they are relevant for, and how they may impact a good life for households. Furthermore, we consider societal and environmental consequences of using these ideas as approaches to develop household energy resilience. Although we present the ideas one by one, the ideas should be regarded as interconnected rather than isolated and together forming the framework. A summary of the framework can be found in Table 1.

### *4.1. Backup energy sources*

The first idea considers the use of backup energy sources, including storage, as a means for resilience when electricity supply from the grid is limited or unavailable. This includes using electricity that is stored locally or generated from other energy sources (e.g., generators, solar and wind power, or human power), as well as the use of other forms of energy to perform household activities (e.g., using gas or firewood for cooking).

Future scenarios of sustainable energy often include batteries for households to store electricity [3,7,14,15], and research has explored this for example in the form of electric vehicles as backup batteries [24,49], household-level battery energy storage as a backup, or to enable the storage of solar power [4,50]. From a household perspective, this could mean that the experience of using electricity is similar to that in most affluent households today – electricity is always available if the battery automatically takes over when the supply from the grid is cut off or limited. However, household investment costs need to be taken into account [4,51] and scaling up battery storage comes with increased carbon emissions from production and challenges related to needs for scarce resources. On a smaller scale, batteries can contribute to household energy resilience by powering specific products. Battery-powered products such as flashlights and radios were found to be important material elements of household preparedness in Swedish and Norwegian households [45]. While these types of batteries today are mainly used to make electricity-dependent products mobile, they could in a renewable energy future also contribute to resilience by allowing households to keep using products that are important for everyday life when electricity from the grid is not available.

The idea of using various energy sources to complement electricity use from the grid is far from new. It is widely practiced today, although primarily in other forms than using batteries, in places where the supply or price of electricity is unreliable. Examples from studies of households with unreliable electricity connections in Kenya and Zambia include using charcoal, gas or firewood for cooking, having solar panels or solar powered lamps, and using car batteries as a backup source for energy [10,52]. Similarly, backup options for power outages found in households on the Orkney Islands, outside of the Scottish mainland, and in the Norwegian countryside include stoves that can run on wood, gas, coal or oil, and having wood or oil-based heating systems [31,53]. While many of these alternatives provide more reliable sources of energy, they are problematic from other points of view. Firewood, coal, oil, and gas are carbon-intensive, sometimes inefficient, and they emit particles that are harmful to humans. Therefore, scaling up those specific alternative sources may not be the best way of increasing household energy resilience.

Another potential backup energy source, which is used in practice today but less common in future scenarios, is the use of human power for generating electricity or for carrying out activities that normally use electricity. An exception is [54], which discusses low-tech solutions, such as cycling and hand-washing clothes, as means for resilience in a low-carbon energy future. Low-tech solutions can also include hand-powered chargers and bicycle chargers for charging mobile phones [55] and crank radios recommended for household preparedness [56]. In some situations, it may be necessary to use human power to replace electricity for heavier work. Kesselring [10] found in their study of urban households in Zambia that unreliable and expensive electricity resulted in increased manual labour, where young women from poor families often were paid to fetch water or do laundry, which reinforced gender and class patterns. Hence, while human power may contribute to resilience and be a necessary or useful complement to electricity in rare occasions or for smaller everyday tasks, relying on human power to a greater extent to replace electricity may come with risks of negative social consequences.

**Table 1**
Summary of how current ideas of domestic energy use in a renewable energy future may contribute to household energy resilience for different types of disturbances, together with household, societal and environmental aspects to consider. See Sections 4.1–4.4 for details.

| | Means for developing resilience | Potential contribution for types of disturbances | Household implications for 'a good life' | Community & societal considerations | Environmental considerations |
|---|---|---|---|---|---|
| *Backup energy sources* | Household batteries<br>Battery powered products<br>Human powered products<br>Fuels used for electricity production or directly for household activities | Allows for continuing with (prioritised) activities during power shortages or power outages | Requires no to small changes in lifestyles, mindsets and values<br>Requires investments and possibly new skills and changed expectations<br>Some fuels emit harmful particles<br>Physical ability required to use human power<br>May be more time consuming | Risk of reinforcing class and gender roles if relying on human power<br>Possible backup sources and agency are impacted by housing type, e.g., do households have space, are they limited by regulations?<br>Sharing backup energy sources could create or strengthen communities | Production of batteries and other backup products requires resources and results in emissions<br>Some fuels are fossil based |
| *Energy efficiency* | More efficient appliances and systems (needs to be combined with sufficient capacity) | Allows for using more appliances in a limited power scenario<br>Not useful for power outages | Requires from no to small changes in lifestyles, mindsets and values<br>Requires investments<br>Time or performance can be affected | Widely accepted – not questioning norms<br>Some households do not decide on energy efficiency investments themselves, but depend on landlords or collective decisions | Could lower overall energy consumption<br>Risk of rebound effects<br>Production of new appliances requires additional resources and emissions if appliances are replaced earlier than needed |
| *Flexibility* | Changing time of activities<br>Changing place for activities | Allows for carrying out activities before or after power outages and shortages<br>Automated flexibility depends on electricity and may not be useful during power outages | Requires from small to large changes in lifestyles, mindsets and values<br>Different applicability for different activities | Risks of injustice – all households are not equally flexible<br>Changing where activities take place require connections between households or between households and other actors<br>New conditions for other rhythms and social norms needed | Production of technology to automate flexibility requires resources and results in emissions |
| *Energy sufficiency* | Quitting energy-intensive activities<br>Replacing activities<br>Replacing products for smaller/ lower capacity ones (or avoiding upgrading)<br>Appliances with variable power options | Allows for continuing with low-energy or electricity-independent activities during power shortages and outages | Requires significant changes in lifestyles, mindsets and values<br>May have positive effects on wellbeing, time, finances etc.<br>Requires new skills and possibly new products | Controversial topic (in conflict with economic growth ideals)<br>Explicitly considers justice<br>Social and cultural norms impact | Could lower overall energy consumption<br>Risk of rebound effects |

In theory, backup energy sources could mean that households in times of power shortages or power outages do not need to change what they do or when they do something. In practice, however, relying on alternative sources might mean that the amount of available energy is limited, that energy is more expensive, or that an alternative form of energy use is more time consuming or does not produce the same result. Thus, households might have to adjust activities and expectations. Furthermore, being resilient in this way requires having the additional equipment and the fuel, as well as knowledge on how to use them and, especially for human power, the physical ability to use them.

A range of societal considerations further impact households' possibility to use backup sources. For example, different housing types (e.g., a house or an apartment in a multi-family building) provide different ‘frames’ for using backup sources. On the one hand, available space to set up a battery or solar panels, or building regulations, might limit a household. On the other hand, sharing backup sources, such as a generator or battery, might open for a local community to increase resilience together, not only by sharing material objects but also knowledge [57]. Other examples include supporting policies and/or ‘green technology’ subsidies that might boost the adoption of household energy storage solutions, and business models targeting prosumers of for example solar energy who wish to rely on their own generated energy. Similarly, a general push in society to electrify personal transport might create implications for resilience at household level as batteries becomes more common.

### *4.2. Energy efficiency*

Making products and systems more efficient is an approach that has been used for a long time with the aim to reduce overall energy consumption and gain financial savings. It is also central in visions of future energy systems. Promises of energy efficiency justify smart energy systems and smart homes [58,59] and are an important part in the United Nations Sustainable Development Goal of affordable and clean energy (SDG 7). A transition to renewable energy depends on reductions in overall energy use, and efficiency measures are expected to reduce overall energy use by almost a third in the EU by 2030 [60] and has the potential for a 50% reduction in the US by 2050 [61], compared to projected energy use. Energy efficiency can also be considered contributing to household energy resilience since, in a power shortage scenario where power consumption is temporarily limited on a household level, more efficient appliances would allow households to carry out activities they may not be able to with less efficient appliances.

For the household, taking energy efficiency measures often require a one-time action, coupled with an investment, such as changing appliances, insulating a house, or installing automated heating or cooling based on occupancy. Energy retrofitting to reduce the need for heating and air conditioning in homes is estimated to have a potential of reducing overall household energy use by 18% in the US [62] and for the EU, on average 20% reductions in heating could be achieved by cost effective retrofitting measures [63]. For appliances, modelling of increased use of energy efficient appliances suggest that European households can reduce their electricity consumption by 20–40%, with efficiency for computers, lighting and cold appliances expected to improve the most [64].

However, for energy efficiency to support household energy resilience, it also matters at what time of the day appliances with improved efficiency are used. From a resilience perspective, efficiency measures will contribute more if they are targeted at appliances that are used during peak times when the risk of power shortage is the highest. A Swiss study found that electricity use for appliances during the evening peak could be reduced by 38% if all domestic appliances are replaced by the most energy efficient ones [65]. Borg and Kelly [64] also projected potential reductions in peak electricity use from investments in energy efficient appliances, but with results varying greatly between households and with some households even increasing peak electricity use significantly during times of the year.

What difference energy efficiency can make for household energy resilience thus depends on the household and what activities they perform, and will perform in the future, during times when electricity supply does not meet demand. If energy efficiency can contribute, it can be an attractive approach to resilience since it relates to how tasks are accomplished, rather than to what is done. It does require investments, and more efficient appliances may have different performance or complete tasks slower, but in many ways energy efficiency may allow life to go on as usual. However, in the case of power outages, efficient products that still depend on electricity are not very useful, unless there is household backup storage or a source for generating electricity.

There are also a number of risks with energy efficiency as an approach to resilience. Energy-efficiency investments are often motivated by saving money [66,67] and efficiency actions that result in reduced costs have been found to run the risk of rebound effects [68]. Reduced costs may lead to increased consumption of the more efficient product or service or the financial savings may be spent in other ways that increase energy use and carbon emissions [69]. In addition, factors outside of the household may prevent households from having energy efficient appliances, improving housing insulation or optimising energy system operation. People living in rented apartments depend on their landlords for many energy efficiency improvements while homeowners to a greater extent can control their investments, with the downside of having to put up the whole investment cost themselves [70]. In housing cooperatives, households together have to make decisions on investments, which may be difficult and slow [67].

Another risk with energy efficiency, is that focusing solely on the efficiency of appliances risks *reducing* household energy resilience. With the current energy efficiency rating in the EU, emphasis is put on energy use per capacity, even though a large appliance with better energy performance may have a higher power consumption than a smaller one [71]. Hence, from a household resilience perspective, for efficiency to be useful it should be combined with the right capacity. Finally, since improved energy efficiency requires investments in new appliances or other resources, the rate of replacement and the connected environmental impact need to be taken into account.

### *4.3. Flexibility*

Flexibility is the third idea, which involves shifting energy-demanding activities in time to when overall demand is lower, often referred to as demand side flexibility. It is common in research, policy, and industry visions of renewable energy futures [3,5,72,73], typically in combination with price signals, and also in visions created by households [74]. From a household energy resilience perspective, flexibility can contribute by adapting the timing of activities without having to decrease the overall amount of energy used. While it is mainly explored as a way of avoiding grid-level power shortage, flexibility can also be useful in situations of planned or unplanned power outages, where flexibility can allow for carrying out electricity-dependent activities at a later or earlier time.

Not all use of electrical appliances is equally flexible. Appliances running in the background, such as dishwashers, washing machines, electric car chargers, and heat pumps, have been found to have a higher potential for flexibility [75–78]. Flexibility for these appliances could also be supported by different degrees of automation, although automation can be linked to convenience and risks of increased energy use [58]. Cooking and leisure activities, that often include social aspects, were found to be more difficult and undesirable to time-shift [6,75,78,79]. In addition, these activities are commonly performed during peak times and include appliances that make up a significant part of household peak demand [65,79]. Hence, from a household energy resilience perspective, flexibility may not appear as very promising. However, since flexibility has mainly been investigated as something households always can choose to buy their way out of, rather than in relation to disturbances they inevitably will be affected by, little is known about how flexibility could be part of responding to disturbances. A study of Australian families suggests that being flexible may be more acceptable in rare situations and for the common good, such as during heat waves when there is a high risk of power shortage [80].

Flexibility at household level is tightly coupled with how our societies are organised [81] and unless we consider changing our institutional rhythms (e.g., work week, school year and schedules), most households are unlikely to become very flexible in their timing of everyday activities. Laundry, for instance, is often done in relation to both other activities in the home, as well as in relation to existing institutional rhythms [81,82]. Social norms might further impact households' capability to become flexible with certain activities. Again, taking laundry as an example, living in a multi-family building, the norm could be to do the laundry during the day or evening, and not during night [6]. This limits options to perform the same activity during off-peak hours, unless there is a community agreement or regulation to change.

As an alternative to moving an entire activity in time, parts of an activity can be time-shifted. This may be useful for practices where the result is time critical but it matters less when the main part is carried out, such as for cleaning practices [78]. An example of this could be washing machines or dish washers that do the main part of the washing during off-peak times and the last part of the washing cycle just before the user wants to take care of the laundry or dishes.

In demand side flexibility there is a focus on the *timing* of electricity-dependent activities, but flexibility in *where* activities take place could also contribute to household energy resilience. In literature, there are examples of this from more extensive blackouts caused by storms: in Sweden, people utilised temporary crisis services points to shower or fetch water and they carried out important activities at their workplace, family and neighbours [83], and in New York, people went to mobile generators put up in public spaces, or to banks or coffee shops, to charge mobile phones and other devices [84]. Carrying out energy-dependent activities outside of the home can have disadvantages such as being more time consuming, being cumbersome or being less socially accepted, but could contribute to household resilience for important activities during longer power outages or to deal with very time critical activities during shorter power outages. During times of crises, such as blackouts, public service points or other places with electricity can also become spaces for social interaction [84].

In the automated, smart grid vision of flexibility, the household is often imagined to not have to change what activities are performed, how they are performed or the output of the activities. Instead, appliances and systems that are not time critical are automatically switched on and off in a way that is optimal for the grid [6]. However, while this may contribute in terms of reducing the risk of power shortage, such technology still requires power. For flexibility to contribute also to household energy resilience during power outages or times of very limited availability of power, more involvement of the household would be required, for example in terms of prioritising which activities are important and urgent or if there are other places where critical activities could be performed.

Another difference the perspective of household energy resilience brings is that it questions the focus on price as the way to achieve flexibility. According to the Swedish Energy Markets Inspectorate [85], basic principles for demand side flexibility measures include that they should be voluntary for the customer, it should be easy to be flexible and the tariffs and prices should be non-discriminatory. Affordability is also commonly mentioned as an important part of a secure and resilient energy system [23,25,26]. Even if an affordable and non-discriminatory pricing structure is the goal, there are potential inequalities related to pricing as the main model for flexibility. Vulnerable groups, such as low-income households, elderly or people with disabilities, may not benefit as much as other groups from time-of-use pricing due to limited possibilities for flexibility and, if measures are taken to be flexible, they risk having a negative impact on comfort and health [86]. However, results from studies of time-of-use prices' financial impact on vulnerable groups show mixed results and depend on the pricing structure [86–88]. Families with children, and particularly single parents, is another group that have been found to be less flexible and thus less likely to benefit from time-of-use pricing [5,80]. Aiming to support household energy resilience may open for new ways of addressing and enabling flexibility that do not solely rely on pricing. Furthermore, the focus on preserving a good life, despite disturbances, is important to avoid negative consequences that risk affecting some households more severely than others.

### 4.4. Energy sufficiency

The final idea from literature is the emerging discourse of sufficiency. Energy sufficiency attempts to go beyond energy efficiency by suggesting limits to energy use.[1] Darby & Fawcett provide the following working definition: "Energy sufficiency is a state in which people's basic needs for energy services are met equitably and ecological limits are respected" [89]:8. Another slightly more informal definition is suggested by the Energy Sufficiency project and reads: "it's about having enough but not using too much. It's about doing things differently; about living well, within the limits" [90]. As opposed to the other ideas of future energy use, energy sufficiency explicitly stresses the need to consider equality and planetary limits. For most affluent societies and households, adopting such an idea inevitably means a significant reduction in energy consumption is needed if we are to reach the 1.5 °C goal as outlined in the Paris Agreement. The emphasis on equality highlights equally important questions about the accessibility and affordability of energy products and services, where low-income and other vulnerable households risk being excluded in an energy transition and perhaps even indirectly punished [88].

Importantly, energy sufficiency implicitly requires (affluent) households to actively reflect on needs and wants in relation to energy-intensive practices and living a good life [18,91]. The result of such reflection (alone, or in combination with support from e.g., policy and services) could be actions that temporarily or permanently decrease electricity use, including changes in what is done, what types of products are used to do something, and the 'output' of activities. This requires 're-framing' and 're-learning' needs in relation to energy. For example, families that participated in a year's trial of switching their cars to less energy-intensive and more resilient light electric vehicles, such as cargo bikes, went through a significant learning process and had to adjust practices in everyday life [92]. A power outage can also be an opportunity to learn about sufficiency practices, such as different ways of staying warm, and to reflect on and prioritise activities [36].

Other types of sufficiency actions are less radical, such as using smaller or lower-capacity fridges, washing machines and televisions [71]. A more temporary approach to sufficiency may also include having appliances with variable power options that allow households to adapt to current availability of electricity and perform activities faster/with higher performance, and with higher power consumption, when electricity supply is abundant and slower/with lower performance during power shortages. As for energy efficiency, this would require households to invest in new technology. However, resilience through sufficiency can be achieved in many other ways: changed use of existing appliances; getting rid of appliances; or avoiding 'upgrading' to appliances with higher power use or new functionality.

Sufficiency can contribute to household energy resilience in similar

[1] A useful explanation of the difference between energy efficiency and energy sufficiency is provided by Thomas and colleagues: "Energy efficiency reduces energy input while keeping the utility/ services constant. With energy sufficiency, energy input is reduced while the utility/technical service changes in quantity or quality. However, the amount of utility/services should still be 'sufficient' for caring and for the individual" [101]:1125.

ways as energy efficiency, i.e., by allowing households to carry on with activities during times of limited availability of electricity. Practicing sufficiency can also include new ways of doing things that are independent of electricity, or to completely get rid of some energy-dependent practices, and thus increase the resilience also for power outages. Energy sufficiency is, however, not without its challenges. Constantly reflecting about what is sufficient is not easy, especially when there are no existing 'sufficiency practices' and households need to create their own [93]. It is also politically challenging (but not impossible) to agree on what level of energy services is sufficient [89] and households may have different preconditions related to energy use, for example different needs related to indoor temperature [94]. In addition, it can be considered controversial to talk about sufficiency and reduction explicitly, and more acceptable to talk about changed consumption and circular economy [91].

While sufficiency can be practiced in individual households, social and cultural norms in society heavily impact how accepted or feasible a transformation can be. At a societal level, it is therefore important to consider, publicly discuss, and address for example affluence as a driving factor [44]. As stressed in [44]:5, there are "structural barriers to sufficiency-oriented lifestyles, locking in high consumption. These include lack of suitable housing, insufficient options for socialising, employment, transport and information, as well as high exposure to consumer temptations".

Taking a sufficiency approach to energy goes against current norms related to growth, consumption, aspirations, and expectations. However, from a household perspective, less output from an activity is not the same as less value gained from that activity and changing how things are done could provide new value. People taking a sufficiency approach to consumption have expressed positive effects such as freeing up time for other activities, increased wellbeing, and improved finances [91]; reducing internet use may have positive effects on social relations, wellbeing, work productivity and online privacy [95]; and cycling instead of travelling by car provides opportunities for exercise and spending time outdoors [92]. Building on such positive aspects of sufficiency could be a way to integrate practices in everyday life that increase household energy resilience.

Whether sufficiency is about quitting activities, shifting from energy-intensive practices to less energy-intensive ones, or replacing products, there is a risk of rebound effects when households initially save money, time, or feel that they have done enough and then end up consuming more in another domain [96]. However, Sorrell and colleagues [96] conclude that for sufficiency actions related specifically to heating and electricity use, rebound effects appear to be lower than for other types of sufficiency actions. Yet, saving money or time, or doing something good for the environment, are important aspects of engaging in sufficiency practices [91–93], and it would be interesting to know whether benefits related to strengthening household resilience would make a difference for rebound effects.

## 5. Discussion

This paper has suggested a synthesised framework for *household energy resilience* – encompassing a definition merging insight from energy resilience and household preparedness, as well as means to live a good life without constant access to electricity borrowed from four current ideas of future domestic energy use. The framework of household energy resilience thus opens for seeing the proactive role everyday households can play in the transition to a renewable energy future, beyond being reactive consumers, crisis managers, or prosumers making their own independent supply. By accepting minor disturbances in electricity supply that a fully renewable energy system might entail, while still feeling able to fulfil everyday activity needs in a good way, households may make a faster transition to renewable energy possible. Thus, in the perspective of this framework, increasing household energy resilience holds a transformative potential in that it can facilitate the energy system to shift to renewable sources and avoid expensive investments in an energy infrastructure with higher reliability.

While all four ideas incorporated into the framework of household energy resilience can contribute to increased resilience at an energy system level in their own way, we see that they together have more potential to enable the 'bounce forward' sought after [41]. The key reason for this is that, at a household level, the transformative potential of household energy resilience lies in the decoupling of the idea of what constitutes a good life from the idea that such a life is dependent on constant supply of electricity. The encompassed ideas contribute to the decoupling in different ways (see Fig. 2): the use of back-up sources decouples a good life from constant *grid-based* electricity supply, efficiency lowers the demand during shortages while sufficiency and flexibility have the potential to decouple a good life from constant electricity supply, independent of source, but flexibility for shorter periods and sufficiency longer and more permanently. These decouplings, and their associated changes in households' activities and artefact ecologies, in turn depend upon and/or impact other transformations in societal norms, energy infrastructure, policy, etc. influencing the demand for (constant) energy supply and ultimately transform the preconditions for and demands on the energy system.

Synthesising the four ideas under the same umbrella reveals both interconnections and tensions, but most of all it reveals a diversity of complementary ideas that can be combined in different ways to achieve household energy resilience, building on diversity as a key aspect of resilience [97]. If the envisioned disturbances become reality, households can utilise them in combination to live a good life. For example, a back-up system may not deliver enough power (to run a washing machine), but the household can be flexible (wash later) or sufficient (air out clothes, or spot clean by hand) in addition. Generally, households' possibilities to be flexible or sufficient reduce the need for back-ups, as the reliance on constant electricity is reduced. However, those possibilities vary across households depending on needs, mindsets, abilities, equipment, and infrastructure, and importantly they differ within households across activities.

Thus, diversity in means for resilience is important for building more complete household energy resilience and to allow households to match means with activity needs or preconditions. One household may already prefer energy sufficient entertainment activities like reading or board games and can easily adopt flexibility in regard to laundry and cleaning, but would have to rely on back-up for communication and work. An initial indication of how the character of activities impact resilience is given in relation to flexibility in Section 4.3, but more research is needed. For the household, being resilient can mean adjusting how things are done, when they are done, and questioning which things get done; changes in both doings and mindsets. In everyday activities they may also have to manage trade-offs and priorities, for example between having to plan and the convenience of using energy reliant products. Building resilience also involves having to act and invest in relation to resilience. Many of the means for developing resilience highlighted in the sections about *back up energy sources* and *energy efficiency* require investments in new products or systems, by households themselves or by e.g., landlords. In addition to constituting a financial burden, such 'material preparedness' requires active engagement from households: households need to figure out which products or systems to invest in (if they can make such decisions themselves), learn how to use them, and to some extent integrate them into everyday life [31,45]. *Flexibility* and *energy sufficiency* may require more significant, although possibly temporary (but repeated), adjustments of practices – particularly concerning new expectations, mindsets and meanings. This can also be challenging for households [92,93] and include both feelings of losing something and finding new values [98].

### 5.1. The household and the wider system

In our definition of household energy resilience, it is related to

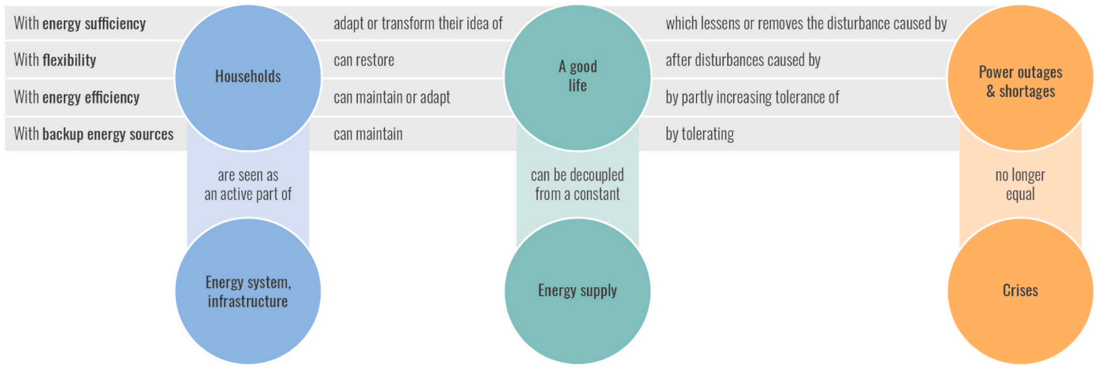


**Fig. 2.** Key points from the household energy resilience framework.

everyday activities performed *within* the household. Yet, resilience is connected to and must be enabled by actors *outside* the household; household energy resilience cannot be separated from developments on an industrial, societal, policy, or infrastructure level and cannot be disconnected from other households or communities [33].

Firstly, in order to enable households to decouple good life from energy dependency, new demands are placed on systems, products, and services to be used in the household. For example, more energy resilient electrical appliances may need to function as 'hybrids' – working both with and without electricity, having different power or performance modes, or using batteries as backup. Furthermore, regulation surrounding products need to change, for example energy labelling needs to take not only energy efficiency into account but also energy sufficiency, so that small appliances with a low energy consumption do not risk being perceived as worse than large appliances, with a higher total energy consumption, that are more efficient per capacity [71].

Additionally, societal discussion and developments may be necessary. For example, flexibility in energy use requires the possibility to be flexible in life [81] (including work, housework, childcare, and social life) while backup energy sources and energy efficiency can require extra time to complete tasks. Flexibility in terms of changing where activities take place requires discussions and policy concerning which places should be prioritised during power shortages, and ways to make these places accessible for people with urgent needs.

All these ways of supporting energy resilience will require shifts in mindsets not only by households but also by other actors and will by necessity be a collective effort. Hence, when applying the framework for household energy resilience it is not enough to involve only households – it is essential to engage also other actors that influence for example policy, infrastructure, products, and systems.

### 5.2. Putting the framework to use

By synthesising the four current ideas of future domestic energy use and extracting their current and potential contribution to household energy resilience, we present an overview of means for exploring and developing household energy resilience (as represented by the first column in Table 1). The overview can concretely be applied as a diagnostic tool to understand current energy resilience in households, allowing for an in-depth understanding across all four ideas. It can also be used with a more formative intent to build resilience, by identifying where households' resilience needs are not met, matching means with activities, and/or investigating barriers currently hindering households to build resilience and their potential to be flexible, sufficient, efficient, and using back-ups. Thirdly, the listed means can be seen as an inspirational 'pick'n'mix' of solutions for actors aiming to support household energy resilience or exploring opportunities and challenges related to disturbances in electricity supply.

The second column in Table 1 provides suggestions for what types of disturbances different means may be relevant for. However, the disturbances need to be concretised for the local context, for example in terms of what time of the day or the year power outages or shortages is likely to occur. In addition, when selecting means for resilience to develop or explore it is necessary to exercise caution, and the last three columns in Table 1 suggest challenges and opportunities to consider related to the different means.

We believe that there is no one-solution-for-all in developing resilience, as everything from daily rhythms, household size, urban or rural context, to policy and infrastructure impact what solutions could support energy resilience in a particular household, for a particular activity, and for a particular type of disturbance. When the framework is applied, such factors must be outlined along with the type of disturbance and energy context that is in focus. Furthermore, as what is, or could be, considered a good life varies between (and within) households and over time, this needs to be explored as well. Our hope is that the framework in this way can open for innovative new solutions, as it allows actors (commercial, public and academic) to engage with alternative ways to enable a good life independent of a constant supply of electricity. Engaging with this decoupling can inspire stakeholders to create new types of systems, products, and services that meet the new demands imposed, and that also in turn allow households to broaden their view of possible actions, investments, outputs, and values.

### 5.3. A tentative framework raising new questions

The framework as it is presented in this paper is tentative in its nature. It builds on a narrative review and therefore cannot claim to have captured all means of and considerations for household energy resilience that can be found in previous research of the four ideas.

Instead, the ambition was to explore how current ways of imagining energy use can be used to advance knowledge and offer new ways of thinking about resilience. The proposed framework, however, needs to be examined and developed with empirical and theoretical studies. From the framework and from insights within the four ideas, challenges and questions for future research can be derived. Specifically, there is a need to further research the connections between the ideas, and in which specific ways they can contribute to building household energy resilience. The discussion thus far has indicated that more knowledge is needed to understand how means can be matched to a) type of disturbance, b) household characteristics, c) activities, and d) social, cultural, and physical contexts. There is likely to be a dynamic interplay between the ideas, where sometimes strengthening connections can be found (e.g. a sufficiency mindset complements the use of efficient equipment), but there may also be conflicts and risks when combining the four.

Further, there is a need for more research on the current state of household energy resilience and how households imagine their own resilience now and in the face of more frequent outages or caps on power use in the future. The reliance on constant energy supply may be hidden to households, either because of the complexity of the systems and products in use every day, or because resilience is backgrounded when the power never fails. In addition, current ideas of crisis management and information regarding preparedness tend to portray a narrow imagination of what could or should be done. Speculative studies (see e.g. [99]) could aid households and other actors in widening their imagination of how resilience could be built in households and society around them. Such studies are important since people's ideas of resilience and of a future with less reliable supply will influence the actions taken that will shape the future.

Adding to the investigation of the state of resilience, it is also valuable to further explore which of the means that are already in play in households, which work, which do not, and which could be accepted given provision of new products, services, or knowledge. The challenges highlighted in the framework concerning for example investments, changes in mindsets and meanings, and potential negative environmental impact also need further investigation.

Furthermore, it is critical to study which factors influence households' possibilities to be resilient in order to address potential barriers. Of special consideration are questions of equity and justice. We have in this paper framed increased household energy resilience as an opportunity, as we are addressing affluent societies in which citizens are likely to take constant supply of electricity for granted [31], as well as be over reliant on that constant supply. Also, it is affluent societies that most urgently need to strive for a good life for all people within planetary limits [44,100], as highlighted in the energy sufficiency literature where questions of equity and justice are raised [89]. However, depending on how energy resilience is supported and carried out, resilience may not be easy for everyone to develop (even in affluent contexts). Therefore, it is important to explore how different measures to support resilience impact different types of households, to provide equal opportunity to become resilient.

## 6. Conclusion

Drawing on existing literature about resilience and domestic energy use, this paper has suggested a new framework for *household energy resilience*. We developed the following definition: *As an interwoven part of everyday life, household energy resilience is to ensure a good life through adjusting what activities that are performed, when they are performed and how they are performed in the face of expected and unexpected power outages and shortages as well as to prepare for future adjustments of activities and to more fundamentally change to reduce the need for adjustments.*

We argue that this framework opens, rather than limits, the space for households to take part in shaping the future energy system and importantly, to become more resilient in an uncertain future. Household energy resilience could be a different starting point for studies or analyses aiming to contribute to knowledge on possible renewable energy futures, that questions the perception of electricity demand as non-negotiable and as well as the current crisis-centred narrative surrounding power shortages and power outages. The tentative framework suggests different means for resilience that can be combined in order to support or explore household energy resilience, as well as household, societal, and environmental considerations that lead to new research questions.

Energy resilience in households will likely not contribute significantly to lowering peaks in demand or shifting loads to off peak hours, unless very energy-intensive activities, such as heating/cooling and charging of electric vehicles, are addressed. But that is not the main purpose of household energy resilience. Instead, we believe that strengthened household resilience could increase the acceptance of an energy system with variable supply and thus potentially facilitate the transition to a fully renewable energy system with more intermittent supply. Household energy resilience might also become a necessity to manage power outages and shortages caused by extreme weather events, as a consequence of climate change.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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