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Erratum

Erratum to “The role of context in residential energy interventions: A meta review” [Renew Sustain Energy Rev 77 (2017) 1146–1168]

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ABSTRACT

Residential energy interventions aim to structurally influence the way people behave in order to achieve a more sustainable behavior. However, the effectiveness of concrete residential energy interventions in specific circumstances varies widely: depending on the context interventions are more or less successful. This paper studies the effect of the context on the effectiveness of concrete residential energy interventions. We do this by means of a large meta analysis of literature. Our review consists of two main parts. First, we give an overview and categorization of all major types of residential energy interventions. Second, we use this categorization to study the effectiveness of different types of interventions in specific contexts: physical (environmental); socioeconomic; cultural; and political and governmental contexts. In addition, we propose to extend well known design methodologies for successful energy interventions by making the role the context plays in these explicit. Our ultimate goal is to provide both practitioners and researchers with a framework that helps with the design of successful energy interventions, hopefully leading to a more sustainable future.

1. Introduction

During the past 40 years, research has been conducted on influencing people towards a more sustainable behavior, with a large body of research that has a particular focus on energy consumption related behavior. Currently, the ideas and the developments of the emerging smart grid reinforce the need for such research. The smart grid is conceived as one of the responses to the worrying climate change situation. This means that interventions aimed at changing the values, attitudes and behaviors of people towards a more sustainable use of energy are especially relevant in the smart grid. There is an increasing agreement that the developments related to the smart grid and smart energy systems cannot and should not be performed without involving or considering consumers or prosumers [43,81,90,91,114,133,145,146,197,204]. The focus of this paper is on residential energy interventions, i.e., those involving consumers (prosumers). Other energy interventions, for example interventions targeted at the industrial sector or the service industry, are outside the scope of this paper.

A majority of the residential energy interventions applied so far present mixed results [85]. Additionally, long-term success and scalability of the residential energy interventions are rarely evaluated. The starting point of this paper is that we believe that the successfulness of interventions depends on the specific context involving a variety of factors. This is in line with a common opinion found in the literature that there is no a silver-bullet type of a solution [82,84,101,102,108,156,191,201,212] and intervention strategies should be carefully designed and attend to the context [80,163,176]. Accordingly, an understanding about the influence of contextual factors to different energy interventions is required. We identify a couple of recent reviews (discussed below) that aim to support this understanding from certain angles. However, a research gap is present regarding a comprehensive picture of the role of context in energy interventions. This paper is written as a response to that research gap.

We analyze different studies considering reported outcomes and the context in which they are conducted. The aim is to provide a starting framework for selecting effective intervention strategies in different contexts. Contexts are categorized into four groups: physical (environmental), socioeconomic, cultural and, political and governmental. While we have considered including technology as another contextual dimension, we select not to do so, as technological factors are largely dependent on the other introduced contexts. Another reason is, as we will see later, that technology adoption (renewable, energy efficient, storage) is usually taken as an intervention target in the framework of

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the smart grid. In addition to presenting success of interventions in different contexts, we craft a set of more general recommendations that the state of the art research is in agreement about. We agree with Kollmuss and Agyeman [123] in that a single model covering all the different factors affecting residential energy interventions' success is not possible or useful. Instead we aim that our research brings more clarity to the existing findings and state of the art and that it can serve as a guide for selecting the most appropriate intervention model in a *particular intervention context*.

Recently, several review papers have been published with a similar aim to the one we describe [80,163,176]. However, the review we present is broader, since it covers all the identified energy intervention targets (see Section 2), while the mentioned reviews focus mainly on awareness, conservation or efficiency. Pothitou et al. [163] present a conceptual framework for behavioral change covering a wide set of factors from micro to macro level, however, they do not discuss the success of interventions under those different factors. Frederiks et al. [80] analyze how individual behavior determinants affect energy interventions. In our framework (see Section 2), such determinants correspond mainly to the internal factors and in part overlap with the socio-economic context. Similarly, Schultz [176] focuses only on a small set of selected interventions and mainly on psychological (internal factors). Hence, the range of factors we cover is broader since we focus on additional external factors, that are not included in those reviews, and we also cover a more comprehensive set of interventions.

The rest of the paper is structured as follows. First, we introduce relevant terminology and concepts (Section 2), following with the description of the methodology of our work in Section 3. Section 4 presents the results of our review, and Section 5 summarizes the role of context in energy interventions. Finally, Section 6 offers concrete recommendations for designing energy interventions based on previous results. Our conclusions and final remarks are given in Section 7.

2. Concepts and terminology

Environmentally significant behaviors are defined as a wide set of activities that directly or indirectly affect the availability of materials and energy and the dynamics of the biosphere [192]. This is an impact-oriented definition, focusing on the behaviors that 'significantly affect the environmental quality' [189]. Psychological research points out an additional perspective, the so called 'intention-oriented definition' [193], that emphasizes the motivations of an individual to act pro-environmentally. The difference between the two perspectives is apparent in cases where people intend to act pro-environmentally, but either fail to do so, or lack proper information, so their actions do not result in a positive impact for the environment [44,193]. Following this, we focus on the subset of environmentally significant behaviors that specifically relate to energy consumption and, depending on the studies reviewed, we consider both of those perspectives: in most of the cases, we consider impact-oriented behaviors, but also sometimes, when talking about internal factors and motivations, we consider the intention-oriented definition.

Precisely, we use the term *energy practices* to describe different human activities that directly or indirectly may lead to end-use energy consumption or prosumption, hence including both conventional and renewable energy (for an overview of residential end-use energy consumption, see Ref. [196]). Energy practices, in our definition, involve an activity, as one aspect, and may or may not involve the resulting energy consumption. Unlike Lopes et al. [129] who use the term energy behavior to represent a similar concept, we choose to talk about practices as they offer a wider meaning and there is a need 'to look beyond energy to understand energy' [30,32,91,162,195]. Practices are embedded deeply in everyday social life [22,32] and 'accentuate the continuity and habituation of activities affected and shaped by social and cultural factors' [174]. Strengers [194] discusses practices instead of people as the sources and carrier of attitudes, values and beliefs. It is also important to remind that there is a potential for some energy practices in our definition that now consume energy to become non-energy practices at a later point.

For describing different solutions, strategies and projects aimed at influencing human energy practices, we use the term *energy interventions*. Diverse energy policies are found suggesting priorities for a sustainable modern energy system [45,46,65,154,203]. Among the suggested priorities are energy conservation and efficiency, exploitation of renewable and sustainable resources, and alternative and emerging technologies. Our review finds that the energy interventions proposed in the literature target all of these priorities and, in addition, some more concrete aspects of human behavior, as we present below.

Practice (behavior) change targets. Examining the literature on energy interventions reveals several categories of practice change targets. First, inline with our wide definition of energy practices, there is a large number of studies focusing on **raising awareness** and fostering discussions on energy topics. An early understanding of researchers was that in order for any behavior change to take place, people first must start thinking more about energy in the context of their everyday life [50,70,132]. However, interventions that solely or mainly focus on raising awareness by increasing knowledge are termed 'information deficit' models and received critique as an overly simplistic approach to behavior change, both from a theoretical and a practical perspective [123,156,188]. Our review reveals (see Section 3) that the largest number of energy interventions proposed is focused on **energy conservation**, also called curtailment or simply saving (usually requires a change in everyday or multiple-time energy practices). Another large subset of the studies targets **energy efficiency** (often one-time practices, such as to buy more efficient devices or apply better isolation). While not always directly contributing to the reduction of energy use, **demand side response (DSR)** is another important target in the context of the modern smart grid that can help to reduce greenhouse gas emissions. DSR 'includes all intentional electricity consumption pattern modifications by end-use customers that are intended to alter the timing, level of instantaneous demand, or total electricity consumption' [5]. Forms of DSR are also sometimes referred to as demand side management (DSM), shifting time of use, efficient demand response, flexibility of energy supply or short-term consumer flexibility. In addition to some suggested technical solutions, DSR is also often achieved through (in combination with) behavior change (e.g. performing energy practices in off-peak hours due to a dynamic pricing incentive). Finally, exploitation of **renewable, sustainable resources and/or storage technology** are structural energy interventions representing another of the suggested priorities in a sustainable modern energy system, that again require a shift in attitudes and behavior change from consumers. In particular, the transition to a distributed production energy system requires from consumers to become *prosumers*, a process that has shown to be slow, among other reasons, due to the required shift in people's attitudes towards energy and adoption of new technology. The promise of energy storage technology is large, especially to support the exploitation of renewable sources.

Energy intervention categories. Energy interventions have also been categorized based on their different approaches. The categorization based on *instrumentality* [59] distinguishes **information-based** (focusing on influencing behavior by providing some novel or differently presented information to consumers) and **structural interventions** (focused on changing the environment in which the behavioral decision takes place). Additionally, we also distinguish as a third category: **gamification and monetary rewards-based** interventions (as they fall in between the first two types). Another categorization of energy interventions is based on the *moment* (point of time) in which they target the behavioral decision [3,69]. The interventions taking place prior to the actual energy practice are **antecedent** and those applied after the activity has taken place are **contingency** (consequence-based) interventions. Finally, based on the *target audience context* [2], we distinguish **individual approaches** that tackle consumers from a psychological and behavioral economics point of view, and **social approaches** that consider consumer's decisions and the social context as tightly interdependent.

Table 1
Practice (behavior) change targets and common types of energy interventions applied.

Practice change target	pro-env. awareness and energy discussion	energy conservation	energy efficiency	demand side management	renewable and storage technology
Example practices	discuss env. and energy topics; understand environmental issues & climate change	unplug devices; shorten showers lower the temp.; line-dry clothes; cold wash	buy eff. devices; heat sensors; weatherization [186]; upgrade HVAC	install home automation; shift time of use; reduce peak use	install solar panels; use battery-rechargeable backpacks; invest in storage
Practice frequency	multiple-time	multiple-time	one-time	multiple-time and one-time	one-time
Example interventions	mass media; communication; social marketing; workshops	energy feedback; prompts; saving tips	discounts for energy eff. devices; tailored audits; eco-labeling	time-of-use tariff; smart-home installation offers; interruptible programs	feed-in-tariff; subsidies for renewable production; community investment
Commonly applied intervention types	information-based; antecedent; individual & social	information-based; contingency; gamification; individual & social	structural; antecedent; monetary incentives; individual	structural; contingency; monetary (dis)incentives individual & social	structural; antecedent; monetary incentives; social

In Table 1 we summarize the categorization of interventions. For each practice change target from paragraph 2 (columns), the table provides concrete examples of practices and interventions (rows). In addition, the last row lists the common categories of the interventions (from paragraph 2) applied for each practice change target. It is important to note that this table serves as a general guide, but that concrete situations where energy interventions are applied are often more complex. The success of different energy interventions has been shown to depend not only on their approaches and targets, but also on different *internal factors* (including motivations, values and attitudes), and *external factors* (such as social, cultural, and physical context) [123].

Internal factors. Psychology-based research [123,197,218] reveals that motivations for people to positively react to behavior-change incentives are exceedingly complex. In addition to motivations, among other relevant internal factors are: existing knowledge, individual sense of responsibility and priorities, values, attitudes, emotional and affective factors.

Contexts (external factors). In this paper, we choose to label the external factors *energy contexts*. Analyzing the role that different contexts play in the success of energy interventions represents the main focus of our review. We identified the following most relevant energy intervention contexts: **physical** (including type of climate, home-ownership, built environment, building automation and type), **socio-demographic** (including family situation and relations, household size, local community and existing cohesion and trust), **cultural** (factors, such as lifestyle, aesthetics, comfort levels, technology savviness), **political and institutional** (including governmental, institutional, jurisdictional and policy factors). We refer to this categorization of contexts as our contextual framework in the rest of the paper; in particular Section 5 is structured based on this framework. It is important to note that the distinction between internal and external factors is not always clear. As can be seen in Section 5, we include in the socio-economic and cultural contexts factors such as pro-environmental motivation, social norms and trust in technology and community. Those factors have apparent internal components. However, due to the social and cultural influences of community to an individual, they also have important external component, and hence we include them in the relevant contexts.

Potential barriers. While the internal factors and contexts discussed above can have different influence on different intervention types, there are certain factors that have been identified to often impede the energy interventions. Such factors are termed barriers to energy interventions. Barriers can affect both internal and external factors. Contexts, internal factors and barriers are discussed in more detail in Section 4, where we analyze and discuss in-depth the literature on existing interventions.

To sum up, energy practices and the everyday life of people are tightly interconnected and a selection of the most appropriate interventions needs to consider the context, internal factors and potential barriers. For example, tackling energy heating primarily through behavior change by conservation is not the most appropriate technique in those cases where upgrading the HVAC (heating, ventilation and air-conditioning) system can bring a much larger energy reduction. Another example is a DSR intervention for energy producers. Producers are likely to adopt the DSR behavior spontaneously if it is necessary for efficient exploitation of produced energy due to intermittent renewable energy sources. On the other hand, DSR will not be necessary if storage technology reaches the point of maturity such that prosumers will be able to store enough energy to perform all their everyday energy practices without requiring power from the main grid. Finally, in some cases, a certain type of intervention may not be applicable at all, so other types need to be considered. For instance, conservation or even shifting time of watching TV or cooking dinner, might not be possible, and so energy efficiency is a better type of intervention to look for in such cases [117].

3. Methodology

In order to identify relevant literature on energy interventions we first searched in the Web of Science, ScienceDirect, Scopus, Wiley

Online and Google Scholar databases for (a combination of) the following keywords: 'energy intervention', 'energy consumption', 'energy efficiency', 'energy conservation', 'intervention context', 'behavior change', 'smart grid intervention', 'power grid intervention', 'energy reduction', 'energy competition', 'DSR', 'renewable technology adoption', 'community energy'. We omitted such papers that did not include a behavioral change component in the energy intervention.

From the obtained literature, we first included in our review in total 35 relevant review papers and reports (secondary research) that summarize the effectiveness of different energy interventions. In the following steps, we included primary (concrete studies, real world trials, interviews and surveys) research papers that are not already covered in those reviews found in the first step. For this reason, most of the primary studies we include are published during the last 5 years. However, we also include older primary research papers if they are cited in some of the obtained reviews and if they offer valuable information on the role of context in energy interventions. Hence, in total, we cover 73 primary research studies. Additionally, we also include papers proposing energy intervention frameworks (36), policy suggestions, discussions and other relevant secondary research papers (45). This led in total to 189 included papers. In addition to journal papers, conference and workshop papers, working papers and technical reports, we also included several books (chapters), PhD theses and online resources.

The included research literature comes from a variety of fields, such as: energy policy (15%), social science (12%), psychology (in largest part: the environmental psychology) (11%), behavioral science (8%), built environment (6%), different subfields focusing on environment (such as education, policy, economics) (15%), computer science and engineering (13%), as well as multidisciplinary research (20%).

To structure the review, we divide the obtained literature in categories focusing on specific practice (behavior) change targets and categories of different approaches to energy interventions (see Table 1). For each of the energy practice change targets, we start from existing *review papers* that discuss appropriate types of energy interventions, if such reviews are present. Importantly, many of the intervention solutions target more than one group of the practices presented in Table 1. Most often we find solutions targeting a combination of changes in energy conservation and efficiency, and many of such solutions premise that increasing the energy awareness of the participants will also indirectly increase the success on the other targets. As for DSR, the literature is more distinctive, only some studies report trials targeting DSR in combination with other behavior change targets. Finally, studies targeting renewable and storage technology and their acceptance most often fall in a separate group, as they require structural interventions, larger investments and are more dependent on the development of technology than the other targets.

In described way, we draw a comprehensive picture of the state of the art in the field of residential energy interventions. Upon analysis of this picture, we offer a set of recommendations for all those seeking to experiment with new (and old) energy intervention strategies and apply them in a particular context.

4. State of the art in energy interventions

This section presents an extensive literature review on energy interventions. We review and discuss different proposed interventions in the context of the smart energy grid that, often along with the technological means or improvements, target behavioral change of (pro)consumers. Environmental and social psychology studies on behavior change for energy efficiency have been conducted since 1970s [23,87,103,179]. Since that time, different other fields have produced their own contributions tackling the question of successful behavior change towards more sustainable from diverse angles and sometimes towards a more or less different goal. This first set of studies, in retrospect, started with looking at individual energy behavior, while more recently, a common understanding is that social approaches are needed, those considering groups, communities and individuals as tightly inter-related in the social context.

The first Subsection 4.1 summarizes the review. Each of the following subsections describes in detail the interventions focusing (mainly) on one of the identified practice change targets outlined in Table 1. For the subsection on raising awareness and increasing knowledge, we select the studies in which that was the main focus (and not used as a side-means in combination with other targets). Since these interventions are mostly applied in combination, one subsection discusses energy conservation and efficiency-type of interventions together. In each subsection, we discuss the contexts in which the studies and interventions are applied and their interplay with internal factors and barriers.

Subsection 4.1 offers an overview of the main internal factors and barriers relevant in each category of the energy interventions. Since the role of context (external factors) is the main focus of our work, we take a separate Section 5 to discuss the findings on relevant contextual factors for each category of interventions. Hence, to a reader not interested in a detailed review, we recommend reading the summary Subsection 4.1 and then Section 5 offering the main results of this paper.

4.1. Summary of the review

As we briefly touch upon in Section 2, *motivations and other internal factors* affect energy interventions. Some of the studies that we review aim to understand and influence the psychological drivers of consumers. However, it turns out that such factors are either difficult to influence or that the outcomes of influencing them are sometimes unpredictable (e.g. attitude-behavior gap [14,123], 'information deficit' model (ibid.), or 'negative spillover' [137]). According to Kollmuss and Agyeman [123], internal factors can be categorized to: motivations (intrinsic and extrinsic), values, attitudes, (tacit) knowledge, environmental awareness (including cognitive, knowledge-based component and affective, perception-based component), responsibility and priorities, locus of control (perception of an individual whether she has the ability to bring about the change), and emotional factors. An additional set of commonly discussed internal factors identified in our review includes: habits and routines, beliefs, self image, in-group identification and personal and social norms (injunctive and descriptive) [2], personal capabilities (such as cognitive [48]). Since this is not our main focus in this study, we do not try to provide an exhaustive categorization of motivations and psychological frameworks on energy interventions (for such discussion we refer the reader, for instance, to review papers [123,218]). Instead, we will use the established frameworks and findings on psychological aspects of energy consumption to connect the identified internal factors to relevant contexts, when possible, and to provide a description of the interplay of those two sets of factors.

We also introduced in Section 2 factors that have mostly been identified to hamper the success of energy interventions, and they represent *potential barriers*. The most common barriers discussed in the literature are: skepticism of people towards climate change and the need for a sustainable lifestyle, distrust of information provided by authorities and institutions, lack of knowledge, feeling of dis-empowerment, laziness, lack of interest [123], the perceived size of impact and inaction by others, perceived low impact of own actions and contribution ("free-rider or licensing effect") [59,121], attitude-behavior gap [14,123,177], old behavior patterns (ibid.), social norms to consume, rebound effect [85,92,203], which in extreme cases may result in Jevon's paradox [6], hyperbolic discounting [163], framing (ibid.), privacy issues with energy data [204], physical and infrastructure impediments, up-front costs [53], and policy barriers. Some barriers are specific to certain energy interventions. For instance, after an incentive is removed, *overjustification* might appear among the participants exposed to it, and their behavior will turn to even less desirable than it was before the intervention [176]. Similarly, competitions might increase preexisting tensions between groups (ibid.).

As a result of our literature review, in Table 2 we summarize the most likely internal factors and barriers that affect energy interventions focusing on each practice change target.

Table 2
Identified most relevant barriers and internal factors affecting different categories of interventions.

Practice change target	pro-env. awareness and energy discussion	energy conservation	energy efficiency	demand side management	renewable and storage technology
Internal factors	intrinsic and extrinsic; people prefer looking green to looking greedy; co-benefits; social norms & influence; tacit knowledge	intrinsic; people prefer being green to being greedy; locus of control; information gathering; fairness; social norms	extrinsic, financial motivations (since already present in buying); interest & trust in technology; social norms;	extrinsic, monetary motivations (since already present in paying the bill); social norms; peer-pressure	intrinsic, env. concern; extrinsic, financial motivations (since already present in buying); trust in technology
Potential barriers	skepticism about climate change; distrust in info by authorities; innate tendency to value immediate over future benefits	comfort and convenience; social norms to consume; disempowerement; free-rider effect	rebound effect; required monetary investment; tendency to conserve psychical effort expenditures; attitude-behavior gap	messy lifestyle; lack of knowledge; free-rider effect; low program participation; managing price volatility; persistence	required monetary investment; policy barriers; slow adoption of technology; attitude-behavior gap; infrastructure impediments

In addition to the categorization based on the practice change targets presented in Section 2, one way to look at different energy interventions is based on their approaches (also introduced in Section 2). The categories based on the approaches taken are not complementary, i.e., one type of intervention may belong to several categories. For that purpose, we summarize the interventions in another way in Table 3.

Both, barriers and internal factors for energy interventions are likely to change in different contexts. For instance, the studies on the 'energy efficiency gap' [8,88] discuss how with contextualized energy policies this barrier can be avoided. When it comes to the internal factors, Wang et al. [212] distinguish egoistic from altruistic behaviors and find egoistic behaviors more likely to be affected by the contextual factors than by the internal (psychological) factors. Their suggestion for the policy makers is to carefully consider intervention context when designing solution strategies that tackle egoistic behaviors.

In Section 5, we discuss such contextual factors for the different energy interventions. For the intervention categories, we will in there refer to Table 3.

4.2. Increasing awareness and pro-environmental values

For the review of awareness strategies, the intention-oriented definition of practices is appropriate. The reviewed studies target increasing people's knowledge, raising their awareness and pro-environmental motivation (with a preamble that this will consequently lead to pro-environmental practices change in terms of impact-oriented definition). We adopt the framework with different levels of public behavior drivers presented in Ref. [134], as it corresponds well with our contextual framework 2.0.0.4. According to Maibach et al. [134] the five levels of behavior drivers that the awareness strategies need to consider are: *individual, social-network, community*, and *local* and *distal place* levels. The individual level deals with motivations of public and hence *internal factors*, while the social-network and community levels correspond to a combination of *socio-economic* and *cultural* contexts in our framework. The local and distal place levels capture together the *physical* and *policy and institutional* contexts in our framework. We start by reviewing strategies that are suggested for increasing awareness, and then continue to discuss different levels of behavior drivers for such strategies.

Awareness interventions. Different antecedent information-based strategies have been applied to influence environmental awareness of the public. Maibach et al. [134] argue for *communication* and *social marketing* inspired by successful strategies from a public health perspective. A recent multinational survey [17] shows that communicating *co-benefits* of addressing climate change may motivate people to act for environmental causes. Co-benefits may be in the form of *development*, including economic and scientific advancements, or *benevolence*, including community caring and moral values. When it comes to engaging the audience in the energy discussion, *tangible* and *public feedback*, *social comparison*, *competition* and *interplay between intrinsic and extrinsic motivations* are found important in the workplace context [160]. In the household context [110], bringing *family values into discussion* and establishing *shared commitments and responsibilities* is reported to be effective. Communicating that certain users plan to adopt a specific energy saving solution can be an important part of marketing [150]. Future visions of a potential media role in raising global awareness for environment are also discussed [13].

Potential barriers and limitations. Maibach et al. [134] report that the majority of studies they reviewed attempted to influence *individual level* population behavior, while community level variables can be far more powerful. They also find a small number of studies targeting *place level drivers* of behavior. We try to respond to this gap in Section 5 by systematically identifying roles that different contexts play in energy interventions and suggesting the most appropriate interventions for those different contexts. The approaches expecting to elicit behavior change through only raising awareness and *increasing knowledge* (without a well targeted and context adapted message) are termed 'information-deficit' models and have proven ineffective [3,22,177].

Table 3
Categories of energy interventions.

social / individual	information-based	gamification and monetary rewards	structural
antecedent	mass media; local messengers; social diffusion; public commitment; group goal setting; social norms; modelling; comparison; reciprocity; workshops; co-benefits commitment; goal setting; tailored audits; energy advisors; saving tips; prompts; reminders; environmental info	monetary nudges; serious games; peer comparison; peer pressure capital grants; financial incentives for insulation/ weatherization/ DSR	community investments; community subsidies; (efficient) defaults make it easy; subsidies for renewable prod.; price incentives; price guarantees; soft loans; legislation for prosumers; discounts for EE devices
contingency	comparative feedback; group feedback personal feedback; advanced energy bill	rewards for participation; competition rewards points, badges; achievement rewards; DSR rewards/penalties	tax-exemptions on community prosumers; classes of consumers feed-in-premiums; prosumer incentives;
combination of both	shared responsibilities community debates/ discussions imaginery; scarcity; loss-aversion; cognitive dissonance	social energy games; competitions; leader-boards personal energy; games/ challenges (goals)/ achievements	legislation for community energy; feed-in-tariffs; EU obligation 2020; quota obligations on min share of renewable; time-of-use tariffs;

Similarly, approaches that solely aim to promote *pro-environmental attitudes* have not shown success in inducing behavior change [209] either.

Individual level (internal factors and motivations). Maibach et al. [134] suggest segmenting a population based on existing *values, attitudes* and *knowledge* and marketing to strategically important audiences. Darby [55] also states that it is crucial to identify a starting point for the awareness message that will be accessible to the largest part of the audience to build upon depending on their *tacit knowledge*. Knowledge is an internal factor that awareness strategies often target to improve. Behaviourism approaches to learning for domestic energy use that are mostly based on providing antecedent information and feedback as external stimulus are criticized by Darby [55]. The author suggests using more effective constructivist approaches, so that *subjective* and *affective* elements to learning and *intrinsic motivations* are considered. The main message is that those actions taken toward increasing energy awareness need to be considered as a part of a *continuing process of learning*, in which different citizens and communities will be found at different stages. Another relevant internal factor for awareness strategies that we introduced earlier is *locus of control*. The study on socio-psychological aspects of using smart meters [96] found that 57% of the respondents never interacted with the newly installed devices signifying the importance of (a lack of) locus of control. In particular, perceived ease of use was not a good predictor of interaction with the smart meters, but only *perceived usefulness*. An important finding regarding emphasizing co-benefits in information campaigns is that it will also motivate actions for individuals who are 'unconvinced that climate change is real' [17].

Social-network level (socio-economic context). This level of behavior drivers can be affected with social influence approaches: targeting *opinion (block) leaders* and central individuals in the social network. An example study is [18], where the authors apply social network analysis and diffusion modeling on a social network formed based on survey data from a city in the U.K. The survey assessed how different households interact on the questions of energy with their community or different agencies. The results place importance on *highly central and trusted groups* (such as the Leeds City Council, or workplaces, family and friends) for the energy awareness roll-out strategies.

Community level (socio-economic and cultural contexts) behavior drivers are, for example: *social norms, group identification* and *collective efficacy*. Studies on environmental awareness and *ingroup norms* [96,136,142] suggest that the dimension of group identification matter: members who are *highly self-invested* in the group (group centrality and group satisfaction) conform more strongly to the group norms about environmental consciousness compared to members who are less self-invested. On the other hand, the dimension of self-definition (how similar members perceive themselves to the rest of the group) did not positively affect the conformity to the group norm. The study [136] concludes that *social norm* awareness interventions should target groups that not only offer membership, but that also elicit *affective group identification*. Applicability to different segments and a multinational population displays a promise that emphasizing *co-benefits* is an awareness strategy that can work in different contexts [17].

Local and distal place level (physical and policy and institutional contexts) behavior drivers deal with increasing availability of respectively local and distal products and services and with removing structural barriers and establishing appropriate public policies. Thus they correspond to local and distal aspects of *physical* and *policy and institutional contexts* in our framework.

Example awareness interventions attending to local place behavior drivers are *local energy initiatives* and *investments*. For instance, according to the DECC [58] report, *involving local schools* to raise awareness for energy projects is effective and helps to prevent local opposition to the project. *Trusted local advisors* are also effective in spreading the message to residents. It is also important how some legislation is framed: sometimes a message for more efficient processes, or improving energy security will be more effective with people than an environmental message, even though the government's main reason for introducing the legislation is environmental [152].

An example study considering distal place level analyzed the sociopsychological aspect of using smart meters [96]. Perceived *distributive justice* is found to affect the awareness and the use of smart meters installed by the utility and local institutions. Distributive justice is defined as the distribution of socially valued goods and resources, in this case, energy. Interestingly, people who perceived a lower distributive justice were more likely to interact with the smart meters, in order to feel more in control (locus of control).

In conclusion, several studies suggest [58,96,134] that effective awareness strategies need to attend to multiple levels of public behavior (different contexts). Finally, to the question why increasing the pro-environmental awareness and knowledge does not directly lead to improved behavior [3,176], the answer is that for behavior change to take place, we must create a habit [62,123] that becomes part of our daily routine and that requires an actual practice of the behavior. This leads us to the other behavior change targets.

4.3. Energy conservation and efficiency

Gardner and Stern [83] classify sustainable energy behaviors to curtailment (corresponds to conservation in our framework) and efficiency. Our review shows that studies often consider energy conservation and efficiency interventions in combination. This is expected as they ultimately have the same goal [53] and combining them is one way to deal with rebound effects. Hilty et al. [106] state this principle as follows: in addition to efficiency, *sufficiency* also needs to be tackled, otherwise overall savings will be diminished due to rebound effects. We apply the categorization to interventions based on their approaches (presented in Section 2) and for each category of interventions we also discuss relevant internal factors, barriers and contexts. Since the categorization is based on a set of non-complementary criteria, many interventions can be classified in several of the categories. Having that in mind, we do not aim to provide a clear division between categories but the discussed interventions below serve as illustrative examples for each category.

Antecedent vs. contingency approaches. A comprehensive review focusing on energy conservation [3], introduces two categories of interventions based on the moment when the behavioral decision is targeted: antecedent and contingency (consequence-based). Antecedent include *commitment, mass media campaigns, information, modeling, goal-setting, workshops* and *tailored home-audits*. It turns out that goal-setting is more effective when combined with feedback. Information, while generally resulting in an increase in knowledge and changes in attitude, is also more effective in changing behavior when combined with other interventions. In particular, tailored energy audits and advice to specific household and personalized information is found most effective (similar results have been reported in other studies [59,73]). Commitment is found to work best when it is public, durable and specific [139]. In the overview of approaches to influence households' energy behavior that utilities and authorities in Sweden apply, Gyberg and Palm [97] find antecedent approaches of providing information on how to act in an energy efficient manner and reduce impact on environment most frequently applied. Consequence interventions include: *individual and group feedback* (can be one-time, daily, weekly, monthly, continuous or historical), *comparative feedback* and *rewards*. The main conclusions from the review [3] are as follows: feedback is effective, especially the more frequently it is given. ¡ has been also shown to work in combination with rewards in a competition. Combinations of individual and comparative (social) feedback reported long-term success.

Internal factors. In an eight month field study [14], environment and health-based messaging (*intrinsic motivations*) as an energy conservation strategy resulted with an 8% higher average savings compared to monetary messages (*extrinsic motivations*). Similar findings resulted from a questionnaire with students and a survey of residents in the Dutch context [28]. Bolderdijk et al. [28] concluded that people prefer to have a *self image as being 'green' rather than being 'greedy'*. The identified five types of personas based on household relation to home efficiency improvements in Ref. [98] suggest subtle psychological effects on energy efficiency interventions.

Barriers and limitations. Adopting energy efficiency measures is often a subject of up-front cost [53] barrier. Wilson et al. [217] discuss why the existing approaches to tailored energy audits do not necessarily lead to renovation decisions and they provide policy suggestions for the future approaches. Even though the reported effects of detailed feedback are mostly positive, counter-effects are also found [137]. Gyberg and Palm [97] criticize a lack of discussion on consumption patterns and lifestyle, in particular *totally rethinking the need for certain types of consumption*. Hargreaves et al. [101] identify limits to change of the respondents in terms of necessary appliances and activities for *just "living the life"*, *comfort*, possible *confrontations between family members* and *global policy* and *social context*.

Contextual factors. According to the study by Asensio and Delmas [14], particularly sensitive to the nonprice incentives (environmental and health based messages) were *families with kids* and the authors explain this finding by concluding that the parents think long term and care about the environment for the future of their kids. Gromet et al. [93] present a study with seemingly contradicting results to the reported success of environmental messaging, pointing out the importance of the intervention context. Namely, they find that *U.S. conservatives* respond negatively to environmental types of messages. However, their response to the energy security messages was positive. A U.S. based meta study of programs for promoting energy-efficiency using eco-labeling [20], as an antecedent intervention to influence buying, reported that government-led programs had much larger success compared to private labels. This result demonstrates the importance of *trust* for consumers, and that they still trust the central authorities (government) more compared to private companies. Another finding is that *appealing and simpler* labels (cultural context) influenced consumer behavior more compared to complex explanations.

Information-based vs. structural vs. gamification and monetary approaches. In the meta-study on different information-based strategies to energy conservation Delmas et al. [59] find the average effect size for different field studies from the selected 59 papers to be 7.4%. The most effective interventions are found to be *individualized audits and consulting*, followed by *feedback* and *peer comparison*, while *monetary feedback* seems to have a negative effect (increased energy use). Explanatory comparison (*imaginery*) illustrating consumption in some tangible terms (such as how many trees are needed to offset it) is found a desired and popular feature in the study by Petkov et al. [159].

Monetary incentives have been reported to successfully motivate behavior change during the experiment's duration in several studies already during the 1980s [69]. The authorities and utilities in Sweden recently tried motivating the conservation behavior through monetary incentives with mixed results [97]. In energy efficiency interventions, success is reported for monetary incentives to buy eco-labeled devices or for favorable mortgage terms to buy energy certified (Energy Star) homes [20]. According to Schultz [176], the likelihood of individuals to respond to the interventions of this type is proportional to the size of the (monetary) incentives.

Reeves et al. [165] built a game Power House to experiment with *gamification* effects on energy efficiency. In addition to the players engaging with energy conservation behaviors in a virtual world, their behavior was afterwards assessed in a real-world trial.

Internal factors. One of the first field studies of homes with smart meters and IHDs (In-Home Displays) [101] finds that the main motivations for participating in an energy efficiency trial are *financial, environmental, technological* (interest in new technology) and *information gathering* (about the energy use). A survey-based paper in the Swedish context [73] reported that both economic and environmental motives play an important role for a household's willingness to increase their daily efforts to save energy. When it comes to monetary incentives, one benefits is that pre-existing levels of individual motivation do not affect such interventions, due to *extrinsic motivations* to the individual [176]. In a study that addresses military homes [140], even though the residents did not pay for the bills, efficiency messages were effective, suggesting social, environmental and other non-financial motivations.

Barriers and limitations. It is important to recall that the results of surveys (such as [73]) and questionnaires might be prone to the *attitude-behavior gap*, as reported by Refs. [14,123,177] (between what people think motivates them and what actually does). When using monetary rewards in energy interventions, significant effects in terms of improved efficiency are found, but they are always *short-lived* [3,69].

Contextual factors. Structural approaches deal with changing the environment in which people take decisions. In accordance with the previously reported results for eco-labeling [20], the study on smart meters in combination with IHDs [101] confirms the importance of the *design and aesthetics* in structural interventions.

Individual vs. social. Most of the early research in this category tries to influence individual consumers. Only recently a common agreement arises that social approaches are required. When it comes to the adoption of *home automation* and *energy efficient technologies*, domestication theory [26] is often applied. This theory discusses adoption of technology from a viewpoint of two-way interaction between the technology and the user. Since the technology is a novelty, until it becomes an aspect of everyday life taken for granted, different phases take place: from commodification, objectification, incorporation to conversion. A study of the smart thermostat, The Nest [221], reports initial success with its *'automated behavior change'* approach, but in the long term people's engagement is lost. Similar behavior is reported with smart energy monitors [102]. These examples raise a question: are there certain efficiency technologies for which we do not want that they become 'an aspects of everyday life taken for granted'? In a recent meta-study, Abrahamse and Steg [2] focus specifically on social influence interventions towards conservation. The authors identify six approaches, ranked in terms of effectiveness from the highest to lowest: *block leaders and social networks*: individuals and communities who spread information inside their social network; *public commitment*: binding to a certain behavior or opinion; *modeling*: the influential individuals who demonstrate the behavior themselves; *group feedback*: used to highlight a collective effort and might enhance the feeling of group efficacy [19]; *socially comparative feedback*: social comparison [77] refers to thinking about information about other people in relation to oneself (descriptive social norms); *use of social norms in feedback provision*: the standards and rules are established about the behavior for the members of a group (injunctive social norms). A review of 20 specific energy efficiency trials in the U.S is presented in Ref. [71]. Edward and Jones [71] term such different trials as competitions (not unexpected considering that competitions are generally more prevalent in the U.S. compared to, for instance, the EU). However, they also point out that many of the programs they describe involve diverse other mechanisms for behavior change, such as (in addition to some of the social interventions introduced above): *social diffusion, reciprocity* and *loss aversion*. Commitment is early on shown to be a strategy with the potential to be gradually increased and so induce relatively long-term conservation [118].

We also look at studies of social energy applications: analyzing their effectiveness [63] and providing design guidelines [159] for future applications. The social energy application developed by Dillahunt and Mankoff [63] featured a *community monitor* with a *leader board* and a *message board* and tips on how to save energy. Not all households decreased energy use and the results were in general mixed with no significant change in consumption. Petkov et al. [159] developed EnergyWiz to evaluate socially comparative feedback for energy conservation. Similarity between the users and the people they compare themselves to is crucial here. Ranking can be achieved by mere grouping of people based on efficiency. In order for social comparison (with peers) to enhance learning, a means of *communication between the participants* is necessary (a feature lacking in EnergyWiz). In addition to the data released publicly by Opower targeting consumer behavior change, there are also several studies confirming the effectiveness of their social normative approach [7,15,54]. One rare long term study is conducted in the U.K. by the Smart Communities project [31]. A London neighborhood (400 households) took part in the study and IHDs are installed. Researchers organized *workshops*, TCI (Thermal Camera Imaging) events and engaged the kids through *cooperation with the local primary school*. This study reports long term engagement, continuing after the two years from the start of the project.

Internal factors. According to Edward and Jones [71], *extrinsic feedback* must be applied very carefully: recognition and prices may enhance *intrinsic motivation* when they are perceived as positive feedback, but not as a means of controlling the participants or the primary goal of participation. In the case of competitions, the focus needs to be on *doing well*, instead of winning (for example, providing recognition for *achieving goals* (goal setting), and for 'most improved' participants, instead for outperforming peers). The study with social energy application EnergyWiz [159], concludes that 'a one size fits all' approach is not suitable. For instance for competitive features, only more competitive participants were drawn to such features. People were also in general suspicious of the measurements and how they will enable *fairness* of competition. A general message is that the solution needs to be designed with consideration for users with different motivations. Similarly to the attitude-behavior gap found in Ref. [14], an influential study [149] on social normative approaches found a discrepancy between what people think that motivates them (such as environmental protection and social good) and what actually motivates them (*social norms*) to conserve energy. Nolan et al. [149] argue that since this motivation is often unconscious it can be used to support the behavior change.

Barriers and limitations. According to a well-known study by Cialdini et al. [39], the application of *descriptive social norms* (e.g. in the case of household energy use would be: 'your neighbors consume X amount of energy') might have adverse effects, and so the intervention needs to also apply injunctive social norms ('your neighbors disapprove consuming more then X amount of energy'). Nolan et al. [149] suggest that many of the survey-based or focus-based studies asking people what motivates them might have *under-detected* social norms or other real motivations. The Nest [221] reports that in the long term, efficiency potential is lost, mainly due to *lost engagement* with the device. Edward and Jones [71] in their review agree that the analyzed trials have been successful in reducing energy use (mostly below 10%), however, a *long term persistence* of the behavior change cannot be confirmed for the majority of the trials (in most of the cases it has not been accessed). Allcott and Rogers [9] find that long-term persistence, while reported generally as a problem, might be achieved through cycles of continuous treatment, so that people gradually develop persistent changes in behaviors. Other important findings from Ref. [71] are summarized as follows: *Scalability* potential exists, but many of the program's are designed for local communities, so taking them to a broader scale is not obvious and requires engagement and motivation from local stakeholders. Also, they find that the effectiveness of social comparison might be *short-lived*. Dillahunt and Mankoff [63] report that the users of their social energy application read through the message board and posts by others, but very few posted messages. Their study failed to successfully *engage members* within a household. Often, the studies are based on experiments with a *small number of participants* (e.g. the field study with EnergyWiz [159] was conducted with [17] students; the workshop-based study [110] involved 7 families).

Contextual factors. A good context for normative messages is when many of the participants are *not already motivated* to engage in target behavior [176]. According to Edward and Jones [71], the context and knowledge of the *target audience* is very important. It is important to create appropriate key strategies for the target audience, without combining too many measures that can cause participants' confusion.

Dillahunt and Mankoff [63] find the following factors to be relevant for social energy applications: *built environment* (that can support or hinder social interaction), *community network relations* (properties of the social network), *context knowledge of the comparison group*, *accountability and adherence to social norms*, *trust* and *length of residence*. Conclusions are that for comparison with others, context is important and that more tightly connected communities are more likely to engage in social-energy applications. Similarly, it has been reported in several other studies [199] and simulated models ([168,215]) that patterns of interaction among household members and occupancy predict their efficiency. Interestingly, in the case of The Nest [221] smart thermostat, *trust* in the technology is achieved, but can have an adverse effect at later stages, as people do not anymore reconsider and reflect on their energy practices. Specifically, this study demonstrates how finding a right balance between *user comfort* and energy efficiency is challenging, but without it, this efficiency is not sustained. The effects of political context on energy conservation interventions are explored in Ref. [49]. This U.S.-based study finds that *political conservatives* are less likely to responds to social normative approach to energy conservation. Costa and Kahn [49] call for targeted social normative approaches instead of generalized peer comparison. A comparative study involving diverse stakeholders is conducted in Norway to analyze four main smart grid demonstration projects in the country [184]. The authors find quite different acceptance and interpretation of the technology in the four sites, leading to their main message that smart grids cannot be considered a silver bullet, and that our focus needs to be on finding practical and feasible ways to involve particular users and their *everyday life and knowledge* in the smart grid design. A predictions model based on real energy and socio-demographic data [220] suggests that energy conservation and efficiency gains from employing place-level and social network factors may be as effective as home retrofits.

4.4. Demand side response

Demand side response (DSR) is important as it can support grid load balancing, prevent failures and overloads and enable the use of more energy from renewable sources. Regulators and utilities started implementing DSR since the early eighties [51,75]. Different techniques are applied for DSR. For example, sophisticated real-time control of resources is suggested and being tested. Semi-automated solutions combining ICT tools and smart market trading and pricing to encourage consumer behavior change are presented in Ref. [211]. Some argue that one of the main challenges of DSR is on the ICT side [171]. Solutions exist that aim to bypass the consumer [164] or automate the consumption as much as possible [24]. While the question as to the best means of achieving the required DSR in the residential sector remains open, to a large extent, an agreement exists that successful interventions must involve consumers [177]. We focus here on interventions involving consumers and asking them for a certain behavior change.

DSR interventions. Three types of required customer response for DSR are: *reduction of the usage during peak periods* (asking for a change in comfort), *shifting time of use* (asking for changing time of certain activities, such as turning on washing machine at a different time), and *using own produced energy* (asking from consumers to become prosumers) [5]. The classification of DSR interventions provided in Ref. [5] distinguishes *incentive based* and *price based programs*. Incentive based programs can be classical and market based. Classical incentive based programs are direct load control [170], interruptible [200], and voluntary curtailment programs [76]. In direct load control programs, the utilities may switch off the devices of the customer. In interruptible program's, the participants can be cut of when needed to shed the load. Such programs are often based on upfront *monetary incentives* or discounts. In voluntary curtailment programs, participants are asked at certain times to reduce their load to predefined values. Those who do not respond might face *penalties*, an example of application of monetary disincentives for undesired behavior [176]. Interruptible programs are found in many EU countries [200] and also in the U.S. [51]. Market based incentive programs include demand bidding, capacity market, emergency DSR and ancillary services market. Real option, that is applied in other domains requiring resource optimization [226,227], can be applied, for instance, to power generation and ancillary services [169]. In emergency DSR, participants are payed incentives for achieved reductions in times of emergency situations. Participants of ancillary services *bid on load curtailment* and, when bids are accepted, they get payed based on the spot market price. The most successful means of regulating load through consumer behavior change are price based programs [5,57]: *time of day pricing, spot or real-time pricing* and *weather pricing* [200]. An empirical study in Denmark [144] evaluated effects of Nord Pool real time pricing mechanism on DSR and revealed impacts of up to 5 kW per household. The smart thermostat, The Nest, that we discussed in Section 4.3 is an example of an automated behavior change intervention that, in addition to efficiency, targets DSR [155]. Asensio and Delmas [14] report effects of *environmental and health-based messaging* on DSR, in addition to improvements in energy efficiency and conservation. Abrahamse et al. [3] reported success in some studies in load-shifting using *feedback*. Recently, Xu et al. [219] describe positive effects of IHDs on demand response in households with time of day pricing. The overview of thirty different real-world DSR trials in households [57] concludes the following about the success of the DSR interventions: Trials yielded results with the sizes of the shift varying: in day-night response from 0% to 22%, and in peak load response from 5% to 38%. The DSR interventions in order of most to least successful are: automation, monetary in combination with enhanced information, and non-monetary incentives. Consumer response to the interventions was in general positive. Strengers [194] provides a social practice perspective and argues that the peak demand needs to be framed not as an energy problem, but as a household practices issue. This also calls for involving the most relevant actors, such as housing industry and designers, in addition to the consumers themselves, for successful interventions.

Internal factors and motivations. In contrast to the interventions for the behavior change targets discussed before, for DSR, *monetary* motivations seem to be among the most successful. Also there is no conclusive evidence for success of *non-monetary* incentives alone [57].

According to the same report DECC [57], it is also not clear what energy practices the households are *willing to shift*, but consumer response to the interventions was in general *positive*. Studies also report success of *social norms* and *peer pressure* in DSR interventions [124].

Barriers and limitations. Albadi and El-Saadany [5] conclude that promises of DSR interventions are high, but real utility trials often report *low program participation*. For price based interventions, one of the causes for this is *'limited technical assistance provided to help participants manage price volatility'*. A review of DSR interventions in the EU [200] finds the following barriers to DSR: *outdated metering technologies, time of use pricing is still not reaching many customers*, and the *incentives for response are low*, while according to Ref. [57], *persistence* is also sometimes an issue. Most of the current DSR interventions have been narrowly aimed, according to Strengers [194], and inadvertently created a *supply-demand paradigm* that overlooked integral parts of the energy practices. She criticizes current interventions that fail to address the needs and expectations of the household. As an example, if there is a nostalgic attachment to a *domestic tradition* consuming energy, simply suggesting a shift or removal of the tradition practice is not a successful intervention. The policies and regulations that encourage *central heating and cooling* with comfortable thermal levels represent potential barriers to DSR interventions [36].

Contextual factors. Differences in load potential are identified between different *countries* [200]. According to Ref. [57], *low-income* households seem less responsive to DSR interventions. DSR interventions on a neighborhood-level can be more successful than similar programs on a household level [124]. The survey by Carmichael et al. [34] also reports that 40% of respondents would be more likely to join time-of-use tariffs as part of a group than individually. If thinking about heating or cooling consumption, for instance, Strengers [194] argues that we must involve relevant *planners, builders and developers* in the DSR interventions, who so far are often not concerned 'as that is beyond their role'. *Policy measures* can support DSR interventions such as efficiency improvement targets and differential electric pricing in China [225].

4.5. Exploitation of renewable and storage technology

In addition to individual installations of solar panels, other renewable, or storage technology, we recently find an increased number of local community renewable energy initiatives. Individual and community initiatives require different motivations [127] and emerge in specific contexts. Accordingly, we review the interventions on exploitation of renewable and storage technology dividing them to individual and community initiatives.

Individual renewable/storage energy initiatives. Juntunen [115] analyses the changing role from a passive consumer to a more active prosumer. Similar to what we discussed above about home automation and energy efficient technology (see 4.3), he applies domestication theory [26] to the adoption of renewable technology. Interviews and ethnography on large Finnish online forums reveal the forming of proactive energy engagement emerging with renewable micro-production. Identified inventions with sustainable energy [112,115] show that inventive users can speed up the proliferation of renewable technology. One implication for the energy policy suggested by Hyysalo et al. [112] is to invite inventive users for ideation and to help identify barriers for adoption of local renewable energy production. According to the California Energy Storage Alliance (CESA) [10], energy storage is sometimes referred to as the 'holy grail' of energy and there are currently over 125 thousands MW of grid storage installed world wide. The CESA report also finds storage technology more cost effective to combat energy peaking periods than existing natural gas fired peakers and peaking power plants [126].

Internal factors and motivations. According to Katzeff and Wangel [117], prosumers (owners of solar panels and private windmills) indicate as the main motivation *environmental concern*, while *monetary motivation* is not indicated. The *trust in technology* is important and gradually built [115], and then the capacity is scaled up accordingly. The adoption of solar panels among the Irish population reveals that contextual factors can have a large influence on the adoption behavior [42]. Concretely, contextual positive factors (reason for adoption), and contextual negative factors (reasons against adoption or the barriers) may have *influence over the internal factors* (motivations and attitudes).

Potential barriers and limitations. Claudy et al. [42] apply behavioral reasoning theory to reveal the presence of an *attitude-behavior gap* in the adoption of solar panels. Sauter and Watson [173] report a *lack of information and knowledge* and *skepticism of new technologies* as barriers for adoption of renewable technology. While technology development of energy storage for the grid is taking place [68], a wider adoption has been largely impeded by the capital and life-cycle costs [222].

Contextual factors. Adoption of renewable micro-production is country and region dependent. Germany is the leader among larger economies with currently a record 78% of its daily energy demand being met from a variety of renewable sources [213], while in the U.K. that amount is still below 20% [153]. Several small countries recently achieved over 90% energy coming from renewable sources [94,113,166]. In Uruguay, the policy makers point out the key to success being *'clear decision-making, a supportive regulatory environment and a strong partnership between the public and private sector'* [94]. In addition to displaying that the size of the country is an important factor in shifting to renewable production, this example points to the clear influence of policy and institutional factors. In Portugal, for instance, renewable production is often individual and not community-based [155], as is the case in Germany. Claudy et al. [42] analyzed context-specific reasons for consumer decision-making to adopt solar panels. They find that the *context specific reasons can have direct influence to adoption over and above that of attitudes*. This finding offers in part an explanation for the found attitude-behavior gap. The examination of social acceptance of wind energy [74] concludes that it is never predetermined whether local attitudes towards wind power translate in acceptance or opposition and that the wind project developers can recontextualize obstacles as an opportunity.

Community distributed energy initiatives. One definition of community energy is 'a supply- and demand side action to energy'. A more practical definition talks about 'any project involving collective action to buy, manage, save or generate energy' [33]. While the most favorable form of distributed generation is from renewable sources, other forms are also included in this definition, such as localized low-carbon heat and community scale combined heat and power (CHP). When it comes to community energy projects, instead of applying external interventions, we have a potential to analyze existing (self-organized) grassroot projects and learn from them. With this aim the theory of niches of innovation has been applied [67,181]. In The Netherlands, Doci et al. [67] identified three proxies for the transition potential of social innovations in the energy communities: their *generic rules and lessons learned*, support of and *networking with powerful actors* and *heterogeneity of actors* inside the niche. These communities indeed already communicate between themselves and share relevant lessons learned and they also increasingly get support from the government. As for the third proxy – the more heterogeneous the community (niche) is, the more likely it is to expand and become influential. Energy communities are only now emerging, and they are expected to play an important role in the future of the smart grid. Two alternative possible roles that community energy can play in the future from the aspects of policy and decision making are explored in Ref. [107]. Hoffman and High-Pippert [107] describe one vision where only those citizens are involved in community energy projects that are very active and prefer to be involved in an active democratic debate. Another vision they compare to the Barber's notion of strong democracy [21]. What they argue is that the authorities need to proactively decide on the right role of community energy in the future and how to structure the democratic relationships that are required. Discussion on energy storage is unavoidable in studies of renewable energy integration [35,190], in case studies with off-grid electric power systems [116,119,143] and in studies dealing with development of electric vehicle industry [120,158,167,185]. As a concrete example, in response to the recent methane emission in Aliso Canyon underground gas storage facility [47], the California state initiated building a large energy storage facility that will be able to supply daily 2500 homes [205].

Internal factors and motivations. The analyses of existing projects show that people are often involved and engaged in community energy for *'work-related'* gains [107], *pro-environmental* reasons [66] and also *community monetary* gains [107] are important. However, *personal monetary* gains do not seem important [107]. Dóci and Vasileiadou [66] also present the importance of pre-existing *trust and cohesion* in the communities. An argument from the whitepaper by OVO Energy [155] is that community energy can take a leading role towards the distributed energy system because of the *inherent trust* and *local benefits* it brings and because it can support *behavioral change* better than top-down initiatives. A study with 200 Dutch participants [142] of a smart energy transitioning project revealed a correlation between injunctive social norms [40] and the adoption of smart energy technology, and this correlation is stronger for people who identify more strongly with their community [198]. This result is in agreement with studies on influence of in-group identification on collective action.

Potential barriers and limitations. One barrier to community energy is *scalability*. In the review of grassroots communities in the U.K., Seyfang et al. [181] posit that the learning from many local community projects will be aggregated by relevant intermediaries (government, local authorities, utilities etc.) and disseminated through innovation of diffusion (network theories). Their study, however, concludes that currently, intermediaries are lacking resources to meet the support needs of different local community energy groups. Communities are learning from each other, but a good medium of transfer of their knowledge is still lacking. In particular, *tacit knowledge, trust* and *confidence*, which are key for the community energy projects, are not easily translated to new settings. One of the conclusions is that the governments and authorities can learn from the innovations and diversity in communities instead of trying to fit them into existing ways of commercial innovations or finding a single blueprint for success.

Contextual factors. One of the benefits of energy communities presented in Ref. [155] is that they are more effective at reaching more *socio-economically vulnerable households* to engage with energy issues compared to top-down initiatives. It is also found that *locally sourced information* is more likely to have impacts on behavior changes [173] compared to the information distributed from institutions and decision makers. *Online user forums* offer powerful means of engaging proactive users and sharing their innovations in sustainable energy [111]. The differences in community energy adoption among different countries in the EU point to the importance of a *country(region)-level context*. In Germany, that has taken the lead with regard to renewable energy initiatives, communities own 40% of the renewable energy, while in the U.K. this amount is less than 1% [155]. Some countries might hold a negative view of communities, such as Portugal, Greece or Serbia (after communism), and this may potentially negatively influence the proliferation of community energy projects [33]. A positive interplay is evident between policy factors, such San Diego's pledge to become first 100% renewable city in the U.S. [11], and storage technology development and installation.

5. Energy interventions in context

In this section, we put in context the success or failure of different residential energy interventions and draw recommendations about which concrete interventions are successful under which circumstances. We combine the findings from existing literature tackling energy intervention contexts from some angle [22,29,43,80,95,139,163,176,191,197] with our previously presented review in Section 4. For a visual representation, success of diverse energy interventions in predefined contexts is summarized and presented in tables, one for each of the four identified contexts.

The number of factors identified in the literature to affect interventions in each of the contexts is large. Therefore, we select a number of factors that are representative and often discussed in the literature. We aim to be as complete as possible in our coverage, but given the scope of our research full coverage is not possible. In the tables that follow 1,2,3,4, each square of the table provides the reader with the information about the performance of a concrete intervention under a respective contextual factor. The information shows that correlates have been established between the intervention and the factor, so it can potentially have a twofold interpretation.

The first interpretation is that performing the energy intervention (representing the concrete row) has been successful under the contextual factor (the respective column). The reference in the square then points to the primary or secondary research with such a result. This interpretation is relevant for selecting the most appropriate intervention in those cases where the contextual factors are identified, but cannot be affected. For instance, suggesting energy retrofits to low-income households is less effective than with higher-income households. If we target low-income households, that means, we need to select a more appropriate intervention approach to the context. The second interpretation helps to understand which factors would be beneficial for the intervention in those cases where it is possible to affect the contextual factors. In other words, it indicates that performing the intervention under such circumstances is likely to lead to a more efficient result, so the intervention planners should try to enable or select such factors in their trial. For instance, utilities are sending energy saving tips to their customers. Higher-consuming households likely have more space for improvements, and if the utility can identify the right tip, then targeting such customers is more effective. Under both interpretations, a magenta-colored square points that negative (or none) correlates have been established, while the green-colored square points to positive correlates (and in both cases, the reference in the square points to the relevant study with the findings). If the square is yellow-colored, then usually there are two references to the studies with the conflicting findings, or, if there is only one reference present, then it points to a single study in which such conflicting findings are discussed. White squares represent combinations of interventions and context that have not been found in the literature.

Physical (environmental) context. Groups of factors that are of importance with respect to the physical context are:

- *Building factors*: building type (apartment, house, terrace house), automation, built environment and shared space, building energy efficiency performance, ownership (rented or owned);
- *Environmental factors*: climate, urban or rural, neighborhood type;
- *Regional factors*: the size of the area and the population;
- *Household factors:* the energy consumption percentile compared to similar households, length of residence.

Below, we first discuss several findings from the above table, followed by a summary of the physical context factors and their interplay with different residential energy intervention types.

We suggest to the reader to always read the referenced study prior to taking an interpretation of the result from our table. For instance, Arikawa et al. [12] studied attitudes of Japanese after the Fukushima Daiichi Nuclear Disaster. The negative (or none) effect of 'Energy security/co-benefits info' to the people with 'High consumption percentile' is interpreted in our table based on their findings. Namely, they report that the households with high consumption did not take measures to reduce the consumption after the event and were still in favor of nuclear energy, unlike the other households who favored more energy from renewable resources and reduced their own use.

Similarly, the negative (or none) correlates between the factor 'Country size larger or developed' and the 'Environmental information' and 'Energy efficiency for lifestyle' interventions is based on the discussion from Ref. [123] that small and populated countries tend to be more resource conscientious than larger, resource-rich countries.

Interestingly, people from developing countries will rank environmental issues lower, however, they will still rate those issues with the deserved high importance. This displays their awareness and concern about the environment, in addition to many more other pressing issues they face compared to people in the developed countries.

According to the results by Schleich et al. [175], the best response to feedback have residents whose consumption average falls between the 30th and 70th percentile ('Consumption percentile medium') among similar households. While already efficient households might be limited by the achieved lower consumption, it is important to consider and additionally analyze why the highest consuming households did not react to 'Feedback & comparison' as expected in their case (yellow square in the table). The conflicting results where high-consuming households reacted positive to normative feedback are reported in Ref. [78] and suggest the importance of appropriate feedback framing.

The positive correlates that we report between 'Social norms & modeling' and the 'Length of residence' fall under the second type of interpretation of the information in the tables. Namely, in a study with military homes, up to half of the residents were moving away in a year, and that might be one reason why social comparison was not found as effective [140] as reported in several other studies [2,7,38]. Therefore, we suggest to the intervention designers to consider selecting those segments with a higher 'Length of residence' factor when planning an intervention involving (neighborhood) social norms.

Summary. Table 1 suggests that 'Gamification and rewards' interventions have the overall best performance with respect to the physical context (we found no negative effects reported). For the 'Structural' type of interventions, negative effects are found only with regard to 'Rented home' (a factor generally reported to negatively correlate with several types of interventions). All subtypes of 'Information-based' strategies show mixed results. Providing environmental and efficiency information seems to be susceptible to many negative factors. Importantly, while 'Individual & tailored audits & retrofits' are reported as one of the most effective interventions [3,59], the designers should be careful with regard to rented homes in which case they are not always found to be effective.

Socio-economic context. Commonly discussed factors with respect to the socioeconomic context include:

- *Household/family factors*: including household type (kids, couples only, single households, extended family, student household), age of the youngest family member, household size, family confrontations and relations;
- *Economic factors*: income, vulnerable households, country development level;
- *Community factors*: community cohesion, in-group identification, self-investment in the group, trust, and knowledge of the social group.

For a granular division of socioeconomic factors to micro-, meso- and macro-level factors, refer to Ref. [163].

Selecting and naming the contextual factors to be clearly applicable to all the presented interventions was not easy. For example, in the socioeconomic context, the factors 'Community cohesion', 'Knowledge of the social group' and 'Group identification & self-investment' when applying 'Environmental information' as an energy intervention, relate to providing the information through local community and close social network. For 'Competitions' and 'Social energy apps', these factors relate to the other participants taking part in the intervention.

Prior to discussing the interplay of socioeconomic factors with energy interventions, we point to the result by Brandon and Lewis [29] who found that socioeconomic factors have influence on previous (historical) energy consumption, but not on the consumption during the trial itself. However, as can be seen from our table, a number of other studies have reported that such factors indeed influenced the consumption during the intervention itself. Nielsen [148] estimates that 64% of electricity consumption can be attributed to socioeconomic influences and the rest is affected by lifestyle. Senbel et al. [180] find that the energy practices of individuals are more influenced by the socio-cultural context and their peers than their own awareness of the impact of those practices. An interesting research question is influence of regional factors, such absolute energy use decline in China [79], on energy interventions.

Guerin et al. [95] present influences of socio-demographic factors on energy practices based on an overview of the studies since 1975. As one of the results, they find that inaccurate 'folk knowledge' about energy efficiency retrofits ('Individual & tailored audits & retrofits') coming from their community often influences people more than the accurate information from the institutions performing an audit. This result is reflected in our table as the magenta square for the factor 'Trust in community'.

The green square for the 'Competition and rewards' intervention and the 'Community cohesion' factor shows the result by Yim [223] that community cohesion has a positive effect on social competition, while low cohesion may have an adverse effect on this strategy.

Lorenzoni et al. [131] found that older people and higher income people look more favorably to and show more interest for energy efficiency. On the other hand, the younger the youngest family member, the higher household energy consumption is found (ibid.). This might mean that such households have the highest potential for improvement, so their participation is encouraging. As for non-traditional families and younger adults, more efforts are required for inclusive design of energy efficient services.

Perhaps surprisingly, gender is an often reported demographic factor. Women are found less knowledgeable about environmental issues, but more willing to change and emotionally concerned [123]. However, in their review Frederiks et al. [80] find inconclusive literature results about the influence of gender.

Summary. As can be seen from Table 2, the socioeconomic factor most often reported to impede residential energy interventions is 'Low income/vulnerable households'. While several studies show that low-income families might be less likely to engage with energy efficiency trials, other studies suggest that as an opportunity to increase their discretionary income through targeted interventions [131]. The study focusing solely on low-income households [62] finds that their motivations do not differ from higher-income households, while their approaches to save energy can be more creative. Similarly, 'Family confrontations' and 'Descriptive norms and low efforts by others' are reported to have a negative (or no) effect on the energy interventions in most of the studies we reviewed. It seems that none of the intervention types is generally resilient to socioeconomic potential impediments. However, on the level of individual interventions, 'Energy security/co-benefits information', 'Social norms', 'Commitment', and 'Goal-setting' seem to perform well across a set of the socioeconomic factors.

Cultural context. Common factors found important for the cultural context are:

- *Lifestyle*: comfort levels, aesthetics;
- *Tech savviness*: trust in technology, acceptance, experience with using it;
- *Environmental motivations*: current levels of pro-environmental interest, motivation and attitudes, peer pressure to consume.

The context tables, such as Table 2, aim to present general agreement about correlates between different contextual factors and interventions, however, there are often more subtleties involved than we could represent in this way. For instance, while a good graphic design and appealing feedback ('Aesthetics/Vividness') are generally preferred [78], what constitutes a good graphic design of the feedback may vary significantly between individual countries. An example is the difference in results between the studies on feedback design [72,216] where a preferred design in the U.S. was ranked lowest in Norway due to being 'non-understandable' and 'childish'.

Corradi et al. [48] provide a good example where combining energy tips and advice with individual audits makes the second intervention type more effective.

Intervention type	Concrete intervention \ Contextual factors	Rented home	Rural area	Length of residence	Built environment for interaction	Difficult behaviour (effort) required	Country larger or developed	Consumption percentile medium	Consumption percentile high
Information based, Antecedent	Environmental / health info	[86]				[48]	[123]		[8]
	Efficiency for lifestyle	[85]					[123]		
	Energy security / co-benefits info		[212]				[187]		[12]
	Social norms & modelling			[140]	[159]	[197]			[7]
	Prompts & nudges					[176]			[8]
	Commitment					[105]			
	(Group) goal setting & challenges					[4]			
	Individual & tailored audits & retrofits	[85]		[186]		[197]			
Information based, Contingency	Continuous feedback (IHD, SM)					[102]		[27]	[56]
	Feedback & comparison							[175]	[175] [78]
Information-based, Combination	Community discussion			[159]	[159]				
	Cognitive dissonance					[176]			
	Imagery		[89]				[89]		
Gamification & rewards	Monetary incentives	[85]	[212]			[176]	[108]		
	Peer pressure				[135]				
	Competition & rewards					[176]			[37]
	Social energy apps			[63]	[63]				
Structural	Make it easy & efficient defaults					[176]			
	Time-of-use tariffs						[133]		
	Renewable production / consumption	[178]	[66]	[66]			[133]		
	Community projects & investment		[212]				[90]		
	Direct control DSR					[183]			
	Eco-labels / eff. stand.	[85]				[197]	[133]		[8]

Fig. 1. Influence of physical context factors on energy interventions.

We remind the reader that the context tables need to be interpreted carefully. For example, from Table 3 one can conclude that 'Eco-labels' neither work with pro-environmentally motivated (yellow square) individuals, nor with those who are not concerned (magenta square). However, the research outcomes are more subtle. Eco-labeling is reported successful with already motivated and pro-green individuals [86], except if they perceive that the products do not meet their expectations, or the brand image is poor [128]. In this case, the interplay

Intervention type	Concrete intervention \ Contextual factors	Community cohesion	Knowledge of the social group	Trust in community	Group identification & self-investment	Youngest household member (kids)	Family or group confrontations	Low income / vulnerable household	Descriptive norms / low efforts by others	Gender -- female
Information based, Antecedent	Environmental info	[22]	[22]		[22]	[14]	[129]	[62] [86]	[151]	[95]
	Efficiency for lifestyle					[131]	[129]	[131]		[86]
	Energy security / co-benefits info				[142]	[12]				[95]
	Social norms / modelling	[180]	[197]		[197]	[140]				
	Prompts & nudges								[151]	
	Commitment		[2]		[2]					
	(Group) goal setting & challenges	[180]			[180]					
	Individual & tailored audits & retrofits		[186]	[95]	[186]	[99]	[129]	[95] [99]		
Information based, Contingency	Continuous feedback (IHD, SM)						[81]	[148]	[59]	
	Feedback & comparison	[4]	[4]		[180]			[148]		
Information based, Combination	Community discussion	[138]		[138]					[180]	
	Cognitive dissonance									
	Imaginery							[62]		
Gamification & rewards	Monetary incentives							[95]	[59]	
	Peer pressure	[135]	[180]		[135]					
	Competition & rewards	[223]		[159]	[180]		[176]			
	Social energy apps	[63]	[63]	[63]	[180]		[129]			
Structural	Make it easy & efficient defaults									
	Time-of-use tariffs					[90]	[90]	[57]		
	Renewable production / consumption	[66]	[172]	[25]	[66]			[157]	[157]	
	Community projects & investment	[181]	[181]	[181]				[155]		
	Direct control DSR									
	Eco-labels / eff. stand.									[86]

Fig. 2. Influence of socioeconomic context factors on energy interventions.

with a third factor (aesthetics) is also important to consider, and that is why there is a yellow square in the table. In this way, we point the designer also to the subtle literature results that might be relevant for the intervention context.

Interestingly, 'Energy security/co-benefits information' are reported successful with both previously pro-environmentally motivated and individuals who are not concerned about the environment. For a detailed analysis of public perception of energy security risks, refer to

Refs. [60,187]. In the U.K., Demski et al. [60] found that the energy security concern is generally high, but more susceptible to the contextual factors than the pro-environmental concern. Therefore, a suggestion to the intervention planners employing energy security messages is to investigate the context and accordingly apply the framing effects [202].

Summary. Cultural factors are the most discussed in the literature we reviewed. People's habits, lifestyle and the need for comfort seem to be most often found as barriers to energy interventions. We suggest designing the interventions with least resistance to these factors and employing proper framing of the intervention messages so that people will not feel that their needs for comfort, lifestyle and habits are endangered by it. Technology (availability and savviness), and pleasing aesthetics are, on the other hand, enabling factors for energy interventions. Crosbie and Baker [52] state that 'energy-efficiency interventions must be aesthetically pleasing, stylish and fit with current lifestyles and practices if a significant level of participation is to be achieved'. Once again, 'Energy security/co-benefits', 'Goal setting' and 'Social norms' are found successful across a set of factors. With regard to the cultural context, additionally, promising interventions are 'Imaginery' and (well designed) 'Social energy apps'.

Example additional cultural context factors discussed in the literature that we did not cover in this summary are: stigma [100], hobbies [150] and fashion [182].

Political and governmental context. The factors in this context are sometimes hard to distinguish from some structural policy interventions. We identify the following factors as reported to effect success of interventions:

- political orientation;
- central, trusted institutions and groups;
- distributive justice;
- climate justice.

As before, the reader is advised to interpret Fig. 4 with care. For instance, for the contextual factor 'Central & trusted authorities' the first interpretation of a magenta square might refer to those cases where the existence of trust hampers the concrete intervention. In the second interpretation, the table shows that the non-existence of such trust might represent a barrier. Thus we always refer the reader to the corresponding papers for more precise information about the influence of this factor under their concrete circumstances.

The 'Energy directives (changing)' factor relates to the general policy changes with respect to the introduction of smart meters, consumers, market and efficiency. The factor 'Supportive renewable policy' deals with favorable policy changes directed specifically at individual and community renewable introduction. For a summary on the complex interplay of factors withing the policy context influencing renewable technology adoption, we refer the reader to Ref. [25].

'Distributive (own) justice perception' (or distributive fairness) is another factor that requires clarification. Namely, distributive justice is perceived with socially just allocation of goods [109] (in this case, energy, or energy efficiency technology, or even points in a game). Huijts et al. [109] also distinguish procedural fairness, a factor that we did not include in the table.

Several studies confirm that the effectiveness of eco-labeling programs grows with people learning to trust the labels [49,134] and with an increase of government involvement [20].

Summary. The policy and governmental context factors are mostly discussed for the structural interventions, as expected. These factors seem generally favorable for the 'Gamification & rewards' type of interventions. In addition to 'Energy security/co-benefits', 'Goal setting' and 'Commitment' that we found to perform well in other contexts, 'Individual & tailored audits & retrofits' is an intervention that can be enhanced by the factors in this context. Critical non-favorable factors to address in the policy and governmental context are political orientation (conservatives) and the supportiveness of utility providers. Considering the changing role they face within smart grid systems, finding better ways for involvement with (pro)consumers might be a beneficial strategy to utility providers. Fig. 4 shows that increasing the 'R&D activities', 'Distributive justice perception', passing 'Supportive renewable regulations' and involving 'Central & trusted institutions' in energy interventions are the main policy recommendations to focus on.

For further reading related to this section, we point the reader to following publications [1,4,27,37,41,56,61,89,99,104,105,125,130,135,138,147,151,157,161,172,178,183,206,210,214].

6. Discussion and recommendations

Based on the review above we want to make the role of the context of a residential energy intervention explicit. An observation based on Figs. 1–4 is that research is largely in agreement about the positive effects and negative (or none) effects between certain contextual factors and interventions (as can be seen from a small number of yellow squares, representing conflicting results). On the other hand, a mix of positive and negative (or none) effects are present in all four contexts which illustrates the complexity of the situation. While we could draw several conclusions about successful intervention types under certain contexts (in Section 5), our general recommendation is that the intervention planners need to go to the level of granularity of individual contextual factors and single interventions, in order to craft appropriate intervention strategies.

In particular, we propose to extend the steps for designing successful energy interventions from Refs. [3,139,197] as follows:

1. **Identify the context**: for the energy intervention,
2. **Identify expensive practices**: diagnose the problem by identifying the practices that significantly contribute to environmental problems in the specific context,
3. **Examine internal factors**: motivations, attitudes and perceived abilities of the people involved,
4. **Identify and address barriers**: if possible,
5. **Select interventions**: among those that are found successful under the given contexts and internal factors. Also design interventions that are not negatively affected by the identified barriers, if possible,
6. **Evaluate interventions**: since we need more energy trials to be performed and to learn from their results, future energy interventions need to be designed with evaluation and experimentation in mind.

Identify the context. Pothitou et al. [163] suggest commencing from the local scale (household), through the meso-scale (neighborhood and community), until regional (macro-level) contextual factors for realizing successful energy interventions and policies. We also suggest applying the framework for identifying contexts that is presented in our current paper.

Identify expensive practices. An example study on how to *identify the most expensive energy practices* and guide efforts for energy interventions is described in the following. Yu et al. [224] apply data mining (clustering) to energy consumption data in order to identify the impact of occupant behavior on energy consumption. After identification of seven different factors that influence energy use (*building type and automation, user-related personal, social and economic characteristics, occupant behavior, weather conditions and indoor environmental quality requirements*), the authors select four factors that are independent from the occupants behavior. Based on those factors, they cluster 80 buildings in Japan into four clusters and are then able to isolate consumer behavior effects inside each cluster. A long-term study that examined in detail the energy behavior of residents in New Zealand is presented in Ref. [114]. In addition to knowing the most expensive energy practices, it is important to identify those that involve behavior amendable by a larger number of people [197], otherwise the overall effectiveness would remain small.

Intervention type	Contextual factors / Concrete intervention	Aesthetics / vividness	Lifestyle: comfort required	Trust in technolo-gy solution	Tech availability & saviness	Social norms (e.g. to consume)	Pre-existing pro-env. motivation	Low existing pro-env. motivation	Habits, past be-haviour / trends	Entertainment
Information based, Antecedent	Environmental info	[161]	[161]		[29]	[22]	[176]	[22]	[128]	[161]
	Efficiency for lifestyle	[161]	[52]		[81]	[22]	[128]	[86]	[1]	[161]
	Energy security / co-benefits info		[32]				[12]	[60]		
	Social norms / modelling		[32]					[176]	[161]	
	Prompts & nudges	[151]				[151]	[176]	[197]		
	Commitment					[104]	[176]	[104]		
	(Group) goal setting & challenges	[165]			[84]					[165]
	Individual & tailored audits & retrofits	[89]	[210] [95]	[210]	[210]	[22]			[129]	
Information based, Contingency	Continuous feedback (IHD, SM)	[101]	[90]	[102]	[78]	[201]	[201]	[176]	[9]	
	Feedback & comparison	[78]			[29]		[29]		[9]	[165]
Information based, Combination	Community discussion		[90]					[90]	[90]	
	Cognitive dissonance						[176]			
	Imaginery	[16]			[16]		[89]	[89]		[165]
Gamification & rewards	Monetary incentives		[59]			[59]		[176]		
	Peer pressure									
	Competition & rewards		[59]		[145]	[59]		[176]		
	Social energy apps	[165]			[145]			[176]		[165]
Structural	Make it easy & efficient defaults	[161]				[161]			[206] [161]	
	Time-of-use tariffs		[197]				[90]	[90]	[90]	
	Renewable produc-tion / consumption		[109] [90]	[125]	[125]		[61]		[147]	
	Community subsidies & renew. investment	[61]*		[109]	[109]	[109]	[61]		[147]	
	Direct control DSR		[90]							
	Eco-labels / eff. stand.	[20]	[197]	[197]	[197]	[141]	[128] [86]	[141]		

*Aesthetics in this case refers to peoples' (negative) visual perceptions of wind farms.

Fig. 3. Cultural context factors influence on energy interventions.

Intervention type	Concrete intervention \ Contextual factors	Political conservatives	Central & trusted institutions	Distributive (own) justice perception	R&D activities and investments	Public private partnership	Supportive renewables regulation	Energy Directives (changing)	Utilities supportiveness
Information based, Antecedent	Environmental info	[93]	[95] [22]	[86]	[81]	[130]		[22]	[130]
	Efficiency for lifestyle		[146]		[81]	[146]			[130]
	Energy security / co-benefits info	[93]	[81]	[81]					
	Social norms / modelling	[93]	[81]		[38]				[9]
	Prompts & nudges	[49]			[146]			[146]	
	Commitment				[146]				[105]
	Goal setting				[146]				
	Individual & tailored audits & retrofits		[217]			[217]		[22]	[145]
Information based, Contingency	Continuous feedback (IHD, SM)	[49]	[81]		[146]			[78]	[78]
	Feedback & comparison	[49]	[81]		[146]	[145]		[78]	[78]
Information-based, Combination	Community discussion		[81]						
	Cognitive dissonance				[214]				
	Imaginery				[146]				
Gamification & rewards	Monetary incentives							[146]	
	Peer pressure			[135]				[146]	
	Competition & rewards								[145]
	Social energy apps					[145]			[145]
Structural	Make it easy & efficient defaults								
	Time-of-use tariffs		[156]	[41]	[156]				[156]
	Renewable production / consumption	[61]	[104]		[41]	[94]	[94]	[147]	[104]
	Community projects & investment	[61]	[156]	[109]	[156]	[147]	[61]	[147]	[25]
	Direct control DSR		[41]		[156]				[156]
	Eco-labels / eff. stand.		[49]			[20]			

Fig. 4. Governmental and policy context factors that influence energy interventions.

Examine internal factors. First, we suggest thinking of the aimed behavior change target in terms of energy practices that are most likely to be affected. Then, the energy intervention designers can consider the potential interplay of the energy intervention context and internal factors. According to Clayton et al. [43], more social contexts (such as, trust, norms, group identification) will affect more deliberative and mindful decisions, while less social contexts (such as, physical and technology aspects) will affect more intuitive and automatic decisions related to energy behavior. For a sustained change, the interventions need to target both attitude and behavior (often only the opposite direction is assumed, but sometimes attitude change might actually follow the behavior change). Knowles et al. [122] also offer a radical criticism towards the broadly axiomatic idea that we should design for behavior change for people that simply do not care for the environment. They offer an opposite stance – to design so that a **shift in values** will take place and people will actually start to care. Another suggestion is to target other existing values and apply framing to energy conservation [32]. Segmenting the consumer market according to internal factors is also advised. Midden et al. [141], as an example, argue that environmental messages on products are counter-productive if the 'green' market is still niche. Until the 'green' market grows, they suggest emphasizing other performance attributes.

Identify and address barriers. For example, when it comes to the attitude-behavior gap, people are generally more knowledgeable about topics that interest them and are likely to hold strong attitudes, so one suggestion to deal with this barrier is to influence the interest for (energy) sustainability with people.

Select interventions. A common recommendation is to combine intervention strategies [82,152], while some argue that we must be careful to avoid mixed messages [62,122]. Additionally, we suggest carefully attending to identified contextual factors from the first step. For instance, the trials in Oregon, California, have found that combining communication campaigns with structural and institutional changes (policy and governmental factors) can be effective [152]. Another example why considering context is important is given by conflicting arguments from the literature on employing extrinsic vs. intrinsic motivations discussed below. Swim et al. [197], in the meta-study on psychology of energy efficiency policies, suggest to match external motivators with one-time behavior and intrinsic motivators with multiple behaviors. Moreover, Knowles et al. [122] argue that mixing motivations that are based on intrinsic and extrinsic values (such as pecuniary and reputation) are not effective, as this causes cognitive dissonance in people due to which they do not change behavior. Ockwell et al. [152] and Delmas et al. [59] also note that we must be careful with extrinsic motivations that reduce the reciprocity effect and prosocial motives. One the other hand, Nyborg and Røpke [150] report that intrinsic motivations and monetary ones do not have to contradict, but can reinforce each other. Their study revealed that sometimes consumers can consider the energy price as 'a moral economic indicator of what to do for the common good'. Similarly, Swim et al. [197] discuss a potential benefit of extrinsic motivations in that they might teach behavioral patterns that can be sustained after the incentive is removed. As a solution to these conflicting arguments, we suggest going to the level of a single intervention and the individual contextual factors (as in Section 5). After that, the designers should be able to interpret whether applying intrinsic, extrinsic motivations or combining them is most effective for their selected intervention and under the given contextual factors.

Studies of complex factors effecting energy interventions [80], and those based on user centered design (UCD) [98] argue for personalization in energy interventions. However, for instance, Bailey et al. [16] found no effects of personalization on changes of energy practices during their study with an immersive virtual reality environment. While we do not argue against personalization as an energy intervention strategy, we think this example once more points to the importance of carefully considering the context.

In addition, we think it is important to involve users in each step of the design of an energy intervention, through a participatory design process and formative studies [64], and to shift the perspective from prescription to reflection 30. Another approach suggested in Ref. [150] is the concept of 'the aligned users', as a combination of the involved user in the process and an image of the user that the system targets (with changed energy practices).

The current level of development of technology is promising in designing the interventions (a result we also found when analyzing the cultural context in Section 5). Particularly promising is the application of ICT [33]. Additionally, bringing the ICT sector that already considers users as very important to the energy sector has a potential to shift previous view of consumers (prosumers) as 'loads' to a more human vision of consumers (prosumers) [150].

Evaluate interventions. Designing with experimentation in mind is described in Refs. [152,207,208]. Evaluating the effects of the intervention is particularly important for learning material for future interventions. Additionally, it is important to assess the overall effects of the intervention across different targets. Namely, according to Ref. [137], positive effects on a particular behavior change target (such as energy conservation based on a detailed feedback), might induce negative spillover on other targets (such as decreased energy efficiency investment).

6.1. Limitations of our study

We aimed to select and cover a large body of the most relevant research (see Methodology 3). However, it was not possible to cover all the relevant research and neither to capture all the relevant contextual factors. As presented in Section 5, we have put an effort to select and discuss the most important factors in each of the contexts, but we also point to several other factors discussed in the literature that are not covered in our review. Considering the wide body of research originating from largely different fields, sometimes the use of different or the same terms in those studies is inconsistent, or hard to interpret. In order to ease interpreting the results of this review, we devoted a separate Section 2 to defining the terms as we use them in this paper.

Another potential problem is that of *publication bias*, i.e., researchers are more likely to publish good and impactful results of studies and tend to not publish studies with negative results. This might lead to an underrepresentation of negative results which end up in our tables in Section 5 as white or green squares while potentially being magenta or yellow squares. Unfortunately, we do not have a solution for this phenomena. The conclusions we draw are based on existing literature, and as long as it is harder to publish negative results in scientific publications this effect will be present. We hope to compensate somewhat by also including presentation from other sources, i.e., white-papers and popular press.

Finally, we do not provide or discuss an analysis on financial costs of the programs, in part because most of the research does not provide information on financial resources needed. However, that is another recommendation for the designers of future energy interventions – to include financial statistics in their reports.

7. Conclusions

This paper presents an overview of the current state-of-the-art in residential energy interventions. Such interventions occur in many different forms, and they may or may not work in different contexts. The main contribution of this paper is to identify the relation between residential energy intervention types with specific contexts in order to answer the question: What type of interventions work in which contexts? We show the importance of the context for the (un)successfulness of interventions and argue that designers of residential energy interventions should take context into account in order to increase the success of an intervention.

We hope that the presented study is useful for researchers and practitioners alike in the design of successful energy interventions. Although this paper provides an exhaustive literature review of the importance of context for residential energy interventions, we believe that it only presents a first step. Future studies and interventions should take context explicitly into account, hopefully leading to better and more successful interventions and ultimately to a more sustainable future.

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