Renewable and Sustainable Energy Reviews 183 (2023) 113511

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Reviewing the impacts of smart energy applications on energy behaviours in Norwegian households

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A R T I C L E I N F O

Keywords:
Climate change
Smart digital solution
Residential energy consumption
Sustainable energy behaviour
Technology-based behaviour change
Norway

A B S T R A C T

As climate problems escalate, it is crucial to reduce emissions. Understanding the ability of citizens to engage in decarbonization efforts is vital to address the sustainability challenge posed by climate problems. The potential for emissions reductions through changes in environmentally friendly behaviour is significant but often underestimated. Among many environmentally friendly behaviours, sustainable residential energy behaviours can have a direct impact, as a large share of total energy is consumed in the residential sector, and end-user practices can have a significant effect. As smart technology advances, various digital solutions have emerged for the end-users, significantly influencing their daily behaviour. Notably, smart energy applications have gained increased popularity among these solutions.

This study aims to examine the potential and opportunities of smart energy apps to promote energy-related behaviour change and sustainable practices in the Norwegian context and to provide an overview of the relevant literature.

Our findings suggest a significant lack of empirical research on the effectiveness of energy-related apps in promoting sustainable residential energy behaviour. Additionally, the limited empirical findings that do exist are mainly based on pilot-level projects, with little evidence from population-level adoption. Therefore, further research is needed to gain qualitative and quantitative insights into users' motivations and perceptions and investigate these apps' effectiveness in changing energy-related behaviours and sustaining behaviour change in the residential sector.

1. Introduction

The ongoing climate crisis and the urgency of a sustainable energy transition have prompted policymakers to explore innovative strategies to promote sustainable practices by communities at the citizen or end-user level [1]. According to World Economic Forum [2], 86% of people worldwide want a more sustainable and equitable world after the COVID-19 crisis, and 72% are willing to change their lifestyles significantly. This growing willingness of people highlights the potential for major lifestyle changes in all sectors.

For example, the ongoing energy crisis in Europe has urged many households to adopt energy-saving measures [3]. Residential energy consumption accounts for a quarter of energy use in the European Union [4] and has great potential for emissions reduction. However, energy consumption in the domestic sector is highly dependent on human behaviour and the context in which energy-related decisions are made [1]. To understand the relationship between energy use and human behaviours, past studies have looked into the relevance of sustainable residential energy behaviours from the viewpoint of pro-environmental behaviour. Such studies investigate how residential energy consumption and behaviours contribute to increasing or decreasing carbon emissions and environmental impacts.

With the increasing penetration of digital technology and the widespread use of smartphones, there are now a variety of smart digital tools available to the end-users and individual citizen levels that can influence people's behaviour and transform the context that enables the adoption of sustainable practices as well as decisions. In many areas, particularly in the residential sector, the opportunities to influence energy behaviour through technology have increased significantly due to the availability of smart digital solutions (e.g., smart meters, sensors, smart energy monitors, smart energy apps, etc.) that have brought the opportunities to promote sustainable practices aimed at reducing energy consumption, improving energy efficiency, and helping the demand response of energy systems.

Advances in sensor technology and smart devices such as

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https://doi.org/10.1016/j.rser.2023.113511
Received 3 February 2023; Received in revised form 25 June 2023; Accepted 26 June 2023
Available online 30 June 2023

Abbreviations

AI	Artificial Intelligence
App	Application
COVID-19	Coronavirus Disease 2019
EU	European Union
EV	Electric Vehicle
GDP	Gross Domestic Product
ICT	Information and Communication Technology
iOS	iPhone Operating System
kWh	Kilowatt hour
PV	Photovoltaics
TWh	Terawatt hour
UN	United Nations

smartphones, the Internet of Things (IoT), thermostats, and smartphone-based energy applications have brought the energy sector to the forefront of digital transformation [5]. Such advancement has allowed the integration of technological innovation and human interactivity [6]. This integration has offered great potential to act as an intervention to influence citizens' direct behaviour or daily lifestyles at a demographic scale. Such interventions may influence frequent and direct daily energy practices (e.g., adapting consumption according to the price, shifting consumption to off-peak times) as well as one-off practices or decisions aimed at promoting sustainable energy (e.g., installing solar panels, investing in better insulation, and using energy efficiently).

One of the recent implications of the COVID-19 pandemic is the reported increase in the daily use of digital tools, prompting human behaviour scientists to explore how the increased interaction with digital tools promotes certain ideas, attitudes and behaviours related to sustainable energy consumption [7]. Furthermore, the global issue of energy scarcity and rising prices due to the Russia-Ukraine war has even pressured citizens to reconsider how they consume energy.

This study analyses how and to what extent smart energy apps can promote sustainable energy behaviour, focusing on the context of Norway. The research employs a critical analysis method to achieve four main objectives: 1) to provide a state-of-the-art review of the feedback mechanisms utilised by recent energy apps, discussing their advantages and limitations, 2) to compare the benefits of smart energy apps over other smart solutions, highlighting their practical relevance, 3) to analyse current feedback trends and their implications for the future research directions, and 4) to explore evidence of behaviour change resulting from energy app usage. This study's choice of analysis method is motivated by the need to critically assess the technology-driven sustainable household energy behaviour field, which is still in its infancy. Further, the choice of Norwegian households for in-depth analysis and detailed case study is motivated by its unique context, as its citizens are already familiar with smart energy apps, and the nation is actively encouraging the adoption of sustainable energy practices in various ways. Moreover, the exploration of smart energy apps' adoption and potential impact offers a fresh perspective that has not yet been explored in the literature and provides valuable insights for future empirical research. The analysis and findings of this study have significant implications for utilities, researchers, and policymakers. By understanding the potential of smart energy apps in influencing residential energy consumption and behaviour, this study contributes to the global efforts in addressing climate change, reducing emissions, and promoting sustainable practices aligned with the United Nations Sustainable Development Goals (SDGs), particularly #7 - affordable and clean energy, #11 - sustainable cities and communities, #12 - responsible consumption and production, and #13 - climate action [8].

2. An overview of smart energy apps

Globally, about one-third of final energy consumption is used in buildings [9], while the residential sector accounts for more than one-fifth of the carbon emission [10]. The increasing vulnerability imposed by the rising climate change influences the residential energy consumption pattern as the residents constantly seek to find comfortable and liveable temperatures within their enclaves [11]. Adopting sustainable energy practices in the residential sector can help promote a sustainable energy transition [12]. Therefore, significant behavioural change is needed in this sector. The aim of such behavioural change should be the large-scale adoption of practices such as the implementation of energy efficiency measures [13], the use of sustainable energy sources and technologies, the investment and adoption of energy-efficient appliances, demand response by reducing consumption and shifting the load to off-peak hours [14,15].

Digital interventions are now very common in the energy sector, which uses a variety of interactive smart digital solutions (e.g. domestic energy displays, smart energy apps, web portals and other ambient interfaces) to provide feedback to users about their household energy consumption and additional relevant information [16]. In addition, smart digital solutions enable two-way communication between the energy providers and the end users and provide consumers with comprehendible feedback about their energy usage habits [16].

The literature mentions various digital feedback mediums aimed to influence domestic energy behaviour [17–20]. Much empirical research is conducted on various feedback-based digital interventions, mostly on a pilot scale, confirming the importance of such solutions for achieving desired behaviour change. However, very few studies [17,21] have attempted to study the impact of using smart energy apps employed at the urban scale and the effectiveness of promoting sustainable energy behaviour in households and altering the end-users' energy consumption behaviour. There is also a lack of studies examining end-users' perceptions, motivations, and intentions to use such platforms.

2.1. Literature search

The review is based on a comprehensive literature search using peer-reviewed journals, books, government publications, conference proceedings, and organisational reports. Several major databases were searched, including Web of Science, Scopus, Springer, Oria (University of Stavanger Library) and Google Scholar. Table 1 presents a list of keywords used in the search, various combinations of the listed keywords and the snowballing technique. A focus was placed on smartphone-based energy apps, energy feedback, and energy behaviour, focusing on recent papers to provide an overview of current developments. Due to the relatively recent emergence of smart energy apps, most papers reviewed date from 2015 to 2022, with a few from earlier times. To review the apps utilised in Norwegian households, relevant web publications and the apps themselves were explored. Table 2 presents the basic categorization of the literature referred to for the study.

Table 1
Keywords used for literature search.

Main keywords	Similar keywords
pro-environmental	sustainable, green, ecological, environmentally friendly
energy efficiency	energy conservation, sustainable energy practice, demand response, smart energy behaviour
smart energy apps	smart digital solution, digital technology, ICT
residential energy behaviour	household energy behaviour, domestic energy, end-user behaviour
climate change	carbon emission, environmental impact
promote	encourage, foster, motivate, induce
behaviour change	habit change, behaviour intervention, behaviour disruption
Norway	Nordics, Sweden

Table 2
Categorization of the literature used for references.

Type of Publication	Count	(Author(s), year) [References]
Journal Article	52	(Ajzen, *1991*) [22], (Prochaska et al., 1997) [23], (*Abrahamse* et al., 2005) [24], (Abrahamse et al., 2007) [15], (Hargreaves et al., 2010) [19], (Hargreaves, 2011) [25], (Morris et al., 2012) [26], (Abrahamse & Steg, 2013) [27], (Jabareen, 2013) [28], (Lathia et al., 2013) [29], (Anda & Temmen, 2014) [18], (Chiang et al., 2014) [20], (Grossberg et al., 2015) [30], (Murugesan et al., 2015) [31], (Steg et al., 2015) [14], (Westskog et al., 2015) [32], (Zhao & Balagué, 2015) [33], (Hermsen et al., 2016) [34], (Zhou et al., 2016) [5], (Johnson et al., 2017) [35], (Pfenninger et al., 2017) [36], (Tiefenbeck, 2017) [1], (Antonio & Jean-Philippe, 2018) [37], (Goda et al., 2018) [38], (Silvast et al., 2018) [39], (Winther & Bell, 2018) [40], (Bastida et al., 2019) [41], (Beck et al., 2019) [42], (Geelen et al., 2019) [21], (Goggins et al., 2019) [12], (Iweka et al., 2019) [11], (Piero et al., 2019) [43], (Rist & Masoodian, 2019) [44], (Tsemekidi Tzeiranaki et al., 2019) [4], (Valor et al., 2019) [16], (White et al., 2019) [45], (Zangheri et al., 2019) [46], (Attour et al., 2020) [17], (Chasin et al., 2020) [47], (Niamir et al., 2020) [48], (Ritchie et al., 2020) [10], (Sorrell et al., 2020) [49], (Wolske et al., 2020) [50], (Yuriev et al., 2020) [51], (Askeland et al., 2021) [52], (Benjamin & Markus, 2021) [53], (Chatzigeorgiou & Andreou, 2021) [54], (Sardianos et al., 2021) [55], (Valdmaa, 2021) [56], (Radtke, 2022) [7], (Simonsen et al., 2022) [57], (Veskioja et al., 2022) [58]
Conference Proceedings	3	(Selvefors et al., 2013) [59], (Gargiulo et al., 2015) [6], (Promann & Brunswicker, 2017) [60]
Book	1	Pielke Sr. (2013) [61]
Report	6	(Wachenfeldt, 2009) [62], (Barbu et al., 2013) [13], (International Energy Agency, 2017) [63], (Svenja Binz et al., 2019) [64], (Enova, 2020) [65], (Norsk Industri, 2021) [66]
Newspaper Article	3	(Viseth, 2022) [67], (The Local, 2022) [68], (Lisa O'Carroll et al., 2022) [3]
Web Article	15	(Statistics Norway, 2017) [69], (Statistics Norway, 2018) [70], (Eliq, 2020) [71], (Nordic Energy Research, 2020) [72], (World Economic Forum, 2020) [2], (International Energy Agency, 2021) [9], (Statistics Norway, 2021) [73], (energifakta, 2022) [74], (United Nations, 2022) [8], (Eliq, n.d) [75], (Fjordkraft, n.d.) [76], (Lyse, n.d.) [77], (Tibber, n.d.) [78], (Norway.no, n.d.) [79]

2.2. Smart energy app as a smart digital solution

Smart energy apps are downloadable software applications, mainly for smartphones, that allow users to monitor their energy consumption at home. Today, many energy companies offer consumer energy apps for various purposes, including data collection, analysis, and visualisation of energy consumption, billing, and customer support [1,47]. Furthermore, such apps are now widely used to provide feedback on energy behaviour and to monitor previously unnoticed habits [34]. The chances of disrupting habitual behaviour and sustaining behavioural change are significantly higher when feedback is provided and self-monitoring is possible [34]. Therefore, developing digital solutions for residential energy users at the grassroots level can promote sustainable energy behaviour through behaviour change, such as increased awareness, efficient energy use and participation in the energy market [58].

The frequent interaction with digital feedback from energy apps can foster energy transitions by actively enabling users to participate in the energy market [58]. In particular, technology can change their energy consumption and production behaviour and guide them to greener choices. Ultimately, energy apps can be advantageous for users as they can receive economic benefits from being more environmentally friendly and aware of energy consumption [56,58].

At the city level, although not deliberately adopted through policies, these apps may already be functioning as urban digital interventions to change citizens' eventual energy use behaviour, combining techniques such as feedback systems, prompts, gamification, goal setting, norm appeals, financial incentives, etc. [11]. However, despite its benefits and increasing adoption, research in this area is still scattered and limited.

2.3. Energy feedback and insights

Recently, there has been a growing trend to integrate smart energy apps into behavioural science as the feedback medium for digital behavioural intervention, as smartphones are more integrated with the citizens' lives than any other smart solutions [54]. Recently, some energy companies have used smart energy apps to provide customers with feedback, for instance, detailed usage habits (lighting, heating, charging), consumption patterns, production, social comparisons, weather forecasts, real-time energy prices, AI-based monthly forecasts, carbon footprints, alerts, reminders, energy-related tips, news, quizzes, and updates [76–78]. Furthermore, the integration of machine learning and artificial intelligence in smart energy apps has already surfaced. As a result, they are getting better at learning the household's energy consumption patterns and offering personalised feedback that could considerably impact behaviour change [55]. Such apps provide the necessary information for the users to help decide about energy consumption.

2.4. Benefits of smart energy apps

The smartphone has become the most important tool for individuals, as it is now the most used and preferred device for navigating the internet. According to Statista [80], smartphone users worldwide are growing, from 54% in 2016 to more than 73% in 2020. In countries like Norway, Denmark, and the United Kingdom, the number of users browsing the internet with a smartphone is over 90% of the population. Furthermore, there are many apps based on several themes and sectors. For example, in the energy sector, significant apps are available to individuals for various purposes, especially for end users regarding their residential energy usage. The energy apps integrating with IoT devices such as smart meters, sensors and smart devices can collect granular real-time data on many people's energy consumption and associated human behaviour [1].

Smart energy apps are a relatively newer approach that combines the human aspect and technological innovation, which can intervene in the various energy behaviours to contribute to the development of sustainable cities. According to Pfenninger et al. [36], using behavioural insights of energy consumers is crucial to developing effective energy policies targeting a sustainable residential energy transition. Smart energy apps are considered cost-effective to promote sustainable energy behaviours by providing energy insights to various stakeholders. Moreover, they are beneficial for carrying out large-scale behavioural interventions to drive long-term behavioural changes. Therefore, these apps carry the potential to facilitate technology-driven behavioural change and promote sustainable investment decisions. According to Piero et al. [43], various features of smartphone apps can make the connection between energy consumption and the environment more visible and tangible, and engagement with such apps could raise awareness and induce long-term change. The authors add that data recorded by the smart meters could be displayed directly on the citizen's smartphone interfaces which offers real-time visualisation of the energy consumption data. Furthermore, the market signals and weather data available on the app further allow individuals to adjust their energy use and support demand-side management [64]. Additionally [29], argues that smartphones are the ideal platform for feedback provision and behaviour intervention considering the significant time people spend with their smartphones nowadays.

Energy apps are an inexpensive and relatively simpler digital solution for providing energy feedback compared to dedicated displays in the home, but very few studies have examined the potential of such apps to promote energy behaviour [21].

Energy apps may have promoted sustainable energy behaviour by intervening in energy behaviour, enabling key drivers of behaviour, and removing significant barriers to change [14]. It is, therefore, important to explore the potential of smart energy apps and consider the factors influencing the likelihood of people adopting such behaviour. The residential sector is one of the sectors with significant technology adoption, with smartphones being one of the most popular smart digital tools [63]. Furthermore, some energy apps, as solutions available to citizens/end-users, have integrated some innovative energy-related feedback techniques, such as visualisation and gamification, enabling users to obtain simple and frequent feedback, allowing them to manage their energy resources and residential energy consumption [42,53]. In addition, some apps seek to promote relevant environmental awareness and change people's behaviour and lifestyles in the context of sustainable development [53].

There is a growing trend to incorporate visualisation and gamification elements into apps and the feedback they provide, which makes data easier to understand and helps users to make sound decisions and adopt energy-saving behaviours [37,44]. As a result, such apps are perceived more positively by users regarding behaviour change [42,53]. Fig. 1 shows the main user interfaces of three smart energy applications available on the Norwegian market, giving us an idea of the types of insights these energy applications offers and how they integrate visualisation and gamification features into the applications. As seen, game-like elements such as dashboards, aesthetics, social pressure, referral rewards, avatars, etc., have been integrated into all or at least one of the applications.

In a sustainability context review, (Benjamin & Markus, 2021) assesses games and gamified apps tested in empirical studies and lists those that have yet to be tested [53]. The review notes that gamification has been used in many areas, including energy use, to promote pro-environmental behaviour. It highlights that gamified apps appear to be a promising tool for promoting sustainable behaviour, especially compared to other approaches to behaviour change. Another critical review on gamification in energy apps highlighted that apps with more gamified elements have higher user ratings [42].

2.5. *How do energy apps influence behaviour?*

Several behaviours change strategies adopted in smart energy apps, and the degree of such strategies varies from one app to another. As mentioned earlier, such apps provide a wide range of feedback to influence behaviour. Various feedback from such applications plays a motivating, reinforcing, and enabling role in influencing energy behaviour [41]. Information-based feedback is targeted to bridge the gap between knowledge and action. For example, feedback on energy consumption drives individuals to deliberately change their energy behaviour due to informed consequences [19]. According to research, providing real-time and transparent feedback over an extended period may be more effective [45]. In addition, feedback on similar households can influence residential energy behaviour [27,50].

Energy app-based feedback reinforces a sense of responsibility by enabling users to understand the consequences of certain impacts of their unintentional actions and making them aware of feasible choices [28]. The consumption insights enhance the ability to promote self-efficacy and perceived control. Historical insights can motivate residents to compare two points and establish personal norms [60].

It is expected that future residents as end-users of energy will be more rational, eco-friendly, and cost-conscious than they are today [39], and the feedback through energy apps help the end-user to realise this earlier than it is expected through the channelling of information that could reinforce the responsibility [41]. Providing insights on social comparison could induce perceived social norms [50]. Innovative visualisation and gamification can stimulate learning and improve the user experience, increasing engagement [35].

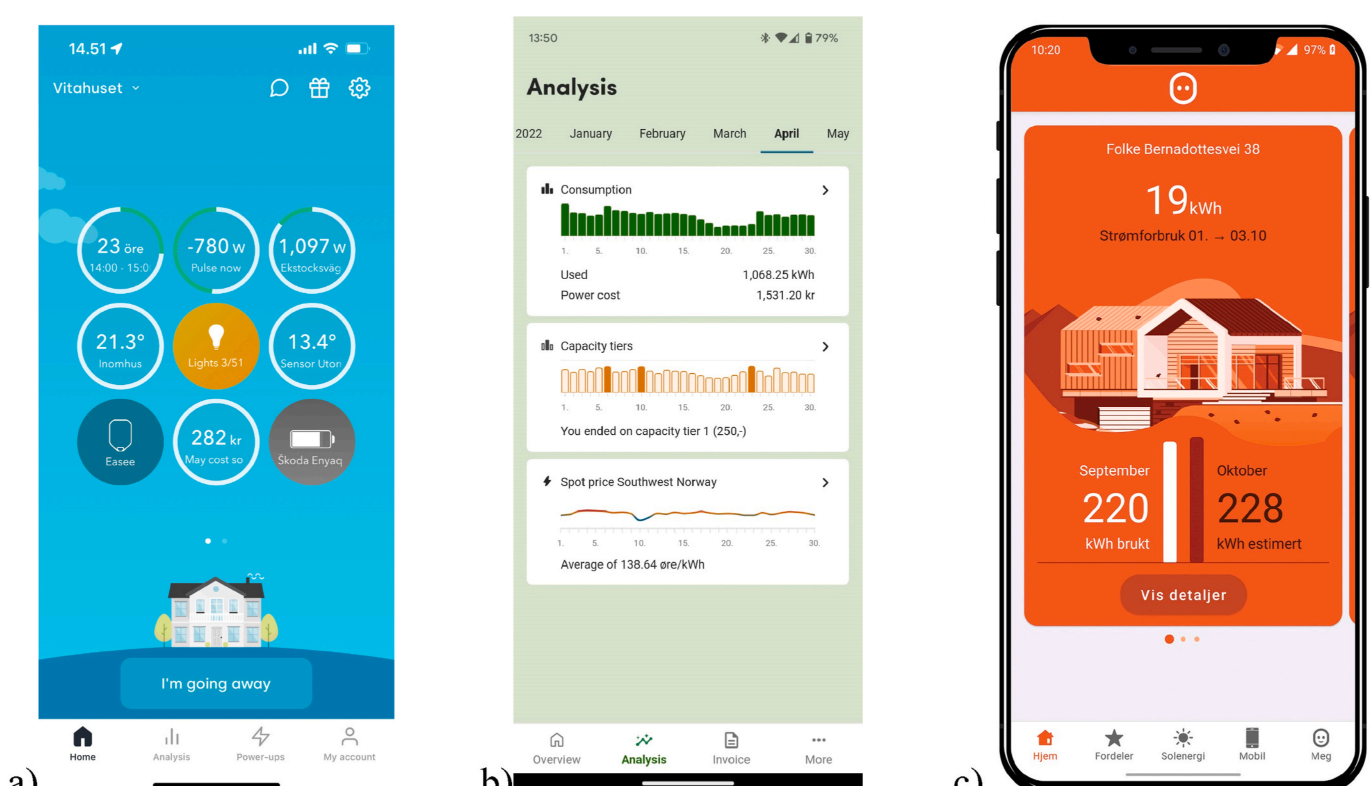

Fig. 1. Main user interfaces of three smart energy apps from the Norwegian market. a) Tibber - Smartere strøm [81], b) Lyse - Min Energi [82], and c) Fjordkraft [83]. (Images used with permission from respective energy companies).

Further, the incentive or the reward mechanism integrated into some applications may motivate users to end bad habits and increase positive ones [45]. The literature mentions several theories and models of individual behaviour and behaviour change, such as the theory of planned behaviour [22,51], the transtheoretical model [84], the social practice theory [25], the diffusion of innovation theory, and others [26]. Furthermore, the different perspectives of these models suggest that individual behaviour results from interactions between people, their environment and technology.

2.6. Energy behaviour studies

According to Abrahamse et al. [24], feedback interventions on energy behaviour can lead to energy savings of approximately 15%, with frequent feedback being more effective. A review by Zangheri et al. (2019) of 64 studies over the past 50 years found that feedback interventions can significantly influence energy consumption [46]. The review analysed empirical data using qualitative methods, considering previous studies, and focusing only on high-quality studies with control groups and minimal confounding variables. Of a total of 127 feedback practices in twenty countries, mostly from Europe and North America, with a duration ranging from two weeks to three years, almost all direct feedback media used was in-home displays, while bills (35%) or mail (25%) were used as indirect feedback media. Overall, the results suggest that tailored feedback is more effective in promoting behaviour change towards sustainable energy use.

While there is a significant number of empirical studies based on digital feedback intervention devices, e.g., smart meters and smart energy monitors [17–20], too few studies [17,21], have exploited the opportunity of smart energy apps to conduct empirical research regarding promoting sustainable energy practices at the city level. Literature highlights the energy invisibility problem and the potential of household energy apps to help occupants monitor and visualize their energy use and adopt energy-efficient behaviour [17]. Furthermore, the role of households in energy transition and bottom-up mechanisms for behavioural change are still poorly understood [48]. Some research has been carried out on home displays and eco-feedback. However, there is little mention in the literature of energy apps and their impact [16]. Geelen et al. [21] claim that their study is one of the first to explore the impact of app use on household energy use, and they conducted a study comprising three studies in the Netherlands. In the first study, energy (electricity and gas) consumption levels were measured over 16 months in a sample of 519 households, divided into an app user group and a reference group. The second study was a questionnaire survey of 270 app users to explore the role of the app in providing insight into household energy use and whether it facilitated behavioural change. The third was an interview with 12 app users. The first study showed no significant reduction in app users' energy consumption level over the study period. However, the questionnaire survey suggested that the app user group reported an increased awareness of energy use compared to the reference group. The interview results suggest that people use the app to track consumption levels rather than to reduce actual usage and further suggest that feedback from the app would be more effective if meaningful information were provided and personalised to the user. Ultimately, the authors recommend further research in this area, as they cannot simply conclude whether the application leads to energy savings.

Likewise, Autour et al. [17] claim that their paper is the first to investigate the determinants of energy-tracking app usage. They mention using evidence from French citizens living in two different urban environments (Nice and Bordeaux), smart cities vs non-smart cities. In their analysis, they created an original survey and used citizen-level data to test a zero-inflated ordered probit model to distinguish between the adoption of smart energy apps and their frequency of use. The results show that the characteristics of smart cities influence the phase of adoption and personal characteristics. Moreover, it was observed that the frequency of use is influenced by concerns related to privacy. Additionally, the emergence of a privacy paradox was discovered in terms of the frequency of use.

Benjamin & Markus [53] mentioned some of the gamified apps within the theme of energy reduction and presented the evaluation of gamified apps highlighting that such apps yield promising results. However, most of them are games rather than feedback-based apps. Nonetheless, evidence from energy efficiency projects in the US validates the positive potential of gamification to encourage long-term sustainable energy behaviour in end-users [30].

Despite the existing literature suggesting drawbacks associated with pursuing energy-sufficiency measures, such as rebound effects and negative spillovers resulting from changes in individual behaviour [49], there is currently a lack of literature investigating the impact of energy app-based feedback interventions on these issues within residential settings.

The inadequate literature hints at a research gap in this field in the global context. Therefore, focusing on the Norwegian context, the upcoming section reviews the literature to understand the relevance and opportunity of smart energy apps as a smart digital solution to promote sustainable energy behaviours among Norwegian residential app users.

3. The Norwegian context

Norwegian society is the centre of discussion since these citizens highly favour adopting smart energy apps for household energy consumption. Meanwhile, Norwegian policymakers and other stakeholders are keen to promote the energy transition and climate neutrality in many ways, including promoting pro-environmental behaviour in the energy consumption sector. For example, the Enova subsidy incentivises individuals to take energy efficiency measures in their homes [65].

3.1. Relevance of sustainable energy behaviour

The Nordic countries are the world's highest per capita electricity consumers at approx. 13,900 kWh/capita, well above the global average of approx. 2800 kWh/capita and the rest of Europe at approx. 5600 kWh/capita [72]. According to Statistics Norway [70], as of 2016, a Norwegian household consumed around 16,000 kWh of electricity, significantly higher than elsewhere. The total energy-saving potential for the private building sector in Norway is estimated to be approximately 12 TWh [62]. Against this background, Norway aims to reduce energy use by 10 TWh in existing buildings by 2030, compared with the 2016 level, which requires various abatement strategies [57], of which energy behaviour change can play a significant part in the sustainable energy transition.

According to Norsk Industri [66], buildings accounted for 34% of Norway's energy consumption in 2020, of which 55% was for residential buildings, highlighting the significant energy demand of the residential sector. Furthermore, as the population increases and GDP per capita grows, the demand for electricity per capita will also increase and therefore, residential energy demand is expected to follow the upward trend, with residential appliances and lighting encompassing everything from chargers, computers, reading lights, dryers, washing machines, refrigerators and more [66].

Norway has pledged to reduce greenhouse gas emissions by at least 40% from 1990 levels by 2030 and is working with the EU and its member states to achieve this goal [79].

There is high hydropower dependency in Norway. While a large share of energy in the building in Norway comes from hydropower, all these hydropower plants are highly dependent on climatic factors such as precipitation and temperature. Norway's overdependence on hydropower will soon become a problem, as events such as record low filling levels of the reservoirs have recently become noticeable, while droughts are taking hold in Norway, resulting in little snow at high altitudes and low water levels in rivers and lakes [67]. Further, hydropower is not carbon neutral, with some studies suggesting significant emissions from the hydropower reservoirs [61].

Unlike many Norwegians who believe that the residential energy they consume comes entirely from Norwegian hydroelectricity [40], the Norwegian energy market is a part of the European energy exchange market, where the electricity is traded with other European countries where the electricity comes mostly from fossil fuels [74]. Thus, lower electricity consumption in Norway means more renewable energy flows to other countries, which could indirectly contribute to a reduction in the overall carbon emission.

Following the war between Russia and Ukraine, electricity prices in parts of Norway have risen to record levels due to domestic factors and import sanctions imposed by the European Union and the United States on Russian oil and gas [68]. The sanctions are affecting energy prices as electricity costs appear to be following international oil and gas prices. To counter rising electricity prices, the government has introduced subsidies on energy bills, but there is strong public resentment about the level of subsidies and how the government is dealing with the electricity price crisis. In this context, the main motivations for household energy efficiency - cost reduction and environmental concerns - previously considered irrelevant [32] now appear relevant in Norway. Furthermore, flexibility in terms of supply and demand is becoming an increasing challenge in Norway as residential consumption patterns change due to the increase in power-intensive appliances (e.g., electric vehicles) and the increase in residential renewable energy prosumers (e.g., photovoltaics) [52].

The ongoing energy scenario in Norway provides insight into the challenges associated with Norway's energy system: such as growing energy demand, a growing portfolio of energy imports, the challenges of managing supply and demand with an increasingly decentralised energy system, the increased adoption of storage technologies such as batteries and electric vehicles [38], the ongoing electricity price crisis and the events such as record low filling levels of the hydropower reservoirs. Adopting sustainable energy behaviour in the residential sector is vital to bear part of the burden of this challenge. In addition, sustainable energy behaviour is a key pro-environmental behaviour that is highly relevant in the residential sector in Norway and elsewhere globally, not only to reduce emissions but also to reduce energy waste, save money and optimise energy systems.

3.2. Potential of smart energy apps in the Norwegian context

Norway has the highest digital skills in Europe, with 9 out of 10 Norwegians regularly sending emails and using online banking [69]. As of 2021, over 98% of people are reported to have access to the internet at home, with smartphones being the most preferred platform [73]. Further, there is also fairly significant internet use by older age groups, with equal proportions of men and women among younger active users who use the internet several times a day. Norway is also considered at the forefront of adopting smart energy technologies, such as smart meters and smart energy applications [7].

3.3. Market scenario of smart energy apps in Norway

Most Norwegian energy suppliers have developed apps enabling customers to visualize, monitor and control their residential energy consumption. As evidenced by the app provision platforms such as the Google playstore and Apple app store, several energy apps are available in the Norwegian market, and such apps have been downloaded and adopted in large numbers at the end-user level. Therefore, three specific apps were analysed to represent the various geographical coverage and ownership models of Norwegian energy providers. Table 3 provides further insights.

Mass adoption of energy apps, as shown in Table 3, highlights that Norwegian citizens are already using these apps as end-users and that there is no need to invest in developing the technical capacity of citizens to encourage the use of such smart digital solutions. However, there is a significant difference in the number of downloads across the Android and iOS platforms. The difference may be due to the factors such as the disparity in affluence levels. While geographic coverage and ownership types also appear relevant, the integration of different features, the level of visualisation and gamification in each of the apps should be explored to understand their impact on the popularity of each app.

Most feedback is standard across the three apps, although some are less common. However, after reviewing all the feedback, it is apparent that the primary focus of these apps is on consumption patterns (Hourly, weekly, monthly, to date this month), forecasts (electricity price, weather, monthly consumption), as well as other information like bills, energy advice, reminders, and others.

Energy companies also offer smart energy apps as a marketing tool to establish their brand in the energy market, and they use consumer app engagement data to understand their energy behaviour better and create added value [33]. Therefore, a review of the three energy apps [76–78] mentioned earlier is made to compare the various features they have integrated. These features can be condensed into three categories: function-centric, feedback-centric, and action-centric, as indicated in Fig. 2.

Table 4 compares the three energy apps - Tibber, Lyse, and Fjordkraft

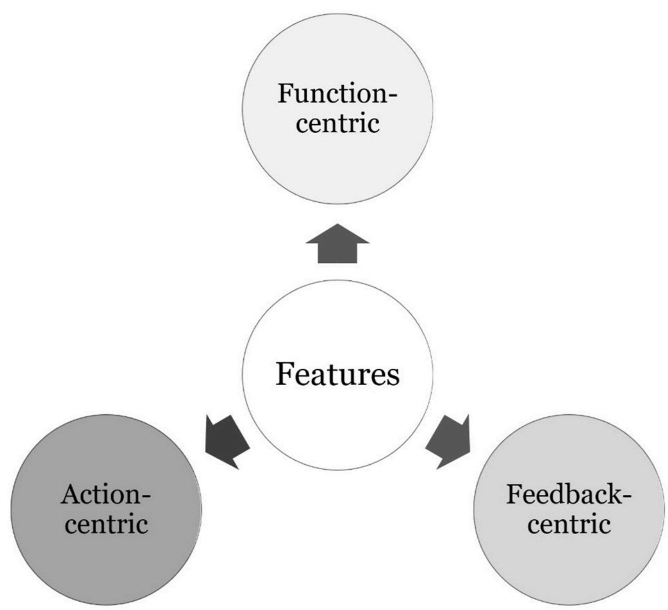

Fig. 2. Classification of features.

Table 3
Three energy apps available in Norway, their geographical coverage, and the number of total downloads [85–90].

Name of energy app	Energy provider	Geographical coverage	Ownership	Number of downloads	
				Android	iOS [a]
Tibber - Smartere strøm	Tibber	Nationwide	privately held with venture capital-backed	500 k+	9.5 k+
Lyse - Min Energi	Lyse	Parts of Rogaland county (Jæren and Ryfylke)	wholly owned by 14 municipalities in south Rogaland	10 k+	29+
Fjordkraft	Fjordkraft	Nationwide	owned by a publicly listed company	100 k+	461+

[a] The presented column displays the aggregate count of app ratings on the iOS platform but lacks download data. However, it is widely known that download figures typically surpass rating counts.

Table 4
Features available within each of the three apps [76]. [77,78].

Features	Tibber	Lyse	Fjordkraft
Function-centric			
Full overview (3)	✔	✔	✔
Transparency (3)	✔	✔	✔
Control (3)	✔	✔	✔
Smart solution (3)	✔	✔	✔
Smart Power management (2)	✔		✔
Digital electricity service (2)	✔		✔
Feedback-centric			
Overview of consumption (3)	✔	✔	✔
Real-time analytics (2)	✔		✔
Carbon footprint (1)			✔
Estimated electricity support (2)		✔	✔
Digital Electricity Price (3)	✔	✔	✔
Overview of invoices (3)	✔	✔	✔
Overview of production (solar PV) (2)	✔		✔
AI-powered personalised insights (1)	✔		
Action-centric			
Gain insight (3)	✔	✔	✔
Take control of your power consumption (3)	✔	✔	✔
Become aware of your electricity consumption (3)	✔	✔	✔
Make informed choices (3)	✔	✔	✔
Connect to smart equipment/power-ups (2)	✔		✔
Distribute power consumption (3)	✔	✔	✔
Reduce electricity consumption (3)	✔	✔	✔
Compare what consumed most (1)	✔		
Compare yourself with others (1)	✔		
Heat your home smartly (1)	✔		✔
Charge your EV smartly (1)	✔		✔

–per the categorization depicted in Fig. 2. The numerical values (3), (2), or (1) associated with each feature indicate whether the feature is common to all three, only two, or exclusive to only one app. The function-centric features highlight the capabilities of each app, while the feedback-centric features give an insight into the types of feedback the apps offer. Finally, the action-centric features are the most note-worthy of all, as they give an idea of the potential energy behaviours that can be shaped through engagement with feedback from the energy apps.

Fig. 3, Figs. 4 and 5 display different app screens for Tibber, Lyse and Fjordkraft energy apps, respectively. These images offer information about the level of visualisation, gamification elements and the type of energy feedback each app offers.

Furthermore, the assessment of the visualisation and gamification elements was conducted by referring to Fig. 3 (Screenshots of Tibber Energy App), Fig. 4 (Screenshots of Lyse Energy App) and Fig. 5 (Screenshots of Fjordkraft Energy App). Additionally, data from Table 4 (Features available within each of the three apps) was utilised to facilitate a comparative analysis of similarities and differences among these apps and the results are presented in Fig. 6.

Tibber was found to have integrated comparatively higher levels of features, visualisation, and gamification, which might be the reason for the higher number of downloads or the higher popularity among the end-users.

3.4. Studies from Norway and Sweden

Several empirical studies [32,59] mention various interactive feedback systems not based on smart energy apps. However, it is essential to analyse these studies to understand what comparative advantages smart energy apps offer in delivering interactive feedback.

In a study by Selvefors et al. [59], an interactive web portal was installed in 23 Swedish households and evaluated in a six-month field study to understand the impact of an interactive energy feedback system. Compared to the previous year, no significant savings in energy consumption were reported during the study period. On the contrary, five households that frequently used the feedback portal reported an average reduction of 9% in electricity consumption. Consumers perceive positive effects (increased knowledge, awareness, and empowerment) towards consumption reduction and behaviour change, regardless of how often they use them. In addition, contextual factors, personal skills, and quality of life also seem to influence household energy consumption, suggesting a positive relationship between frequency of use and savings.

Similarly, Westskog et al. [32] conducted a quantitative analysis to study the impact of in-home displays on daily behaviour and electricity

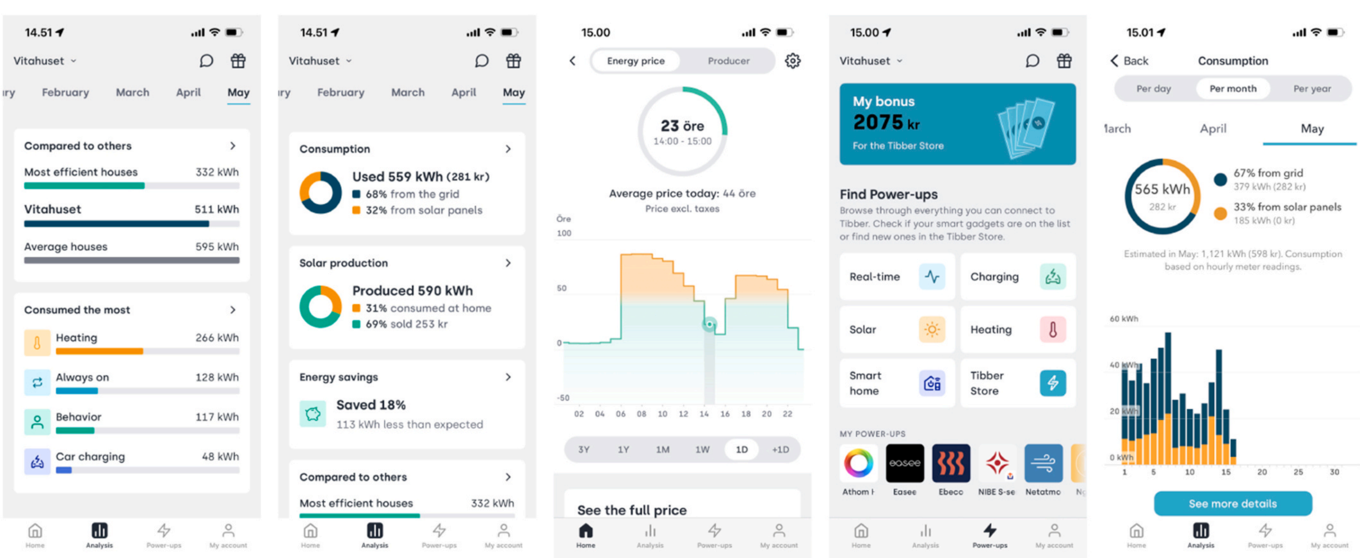

Fig. 3. Screenshots of Tibber energy app - Used with permission [81].

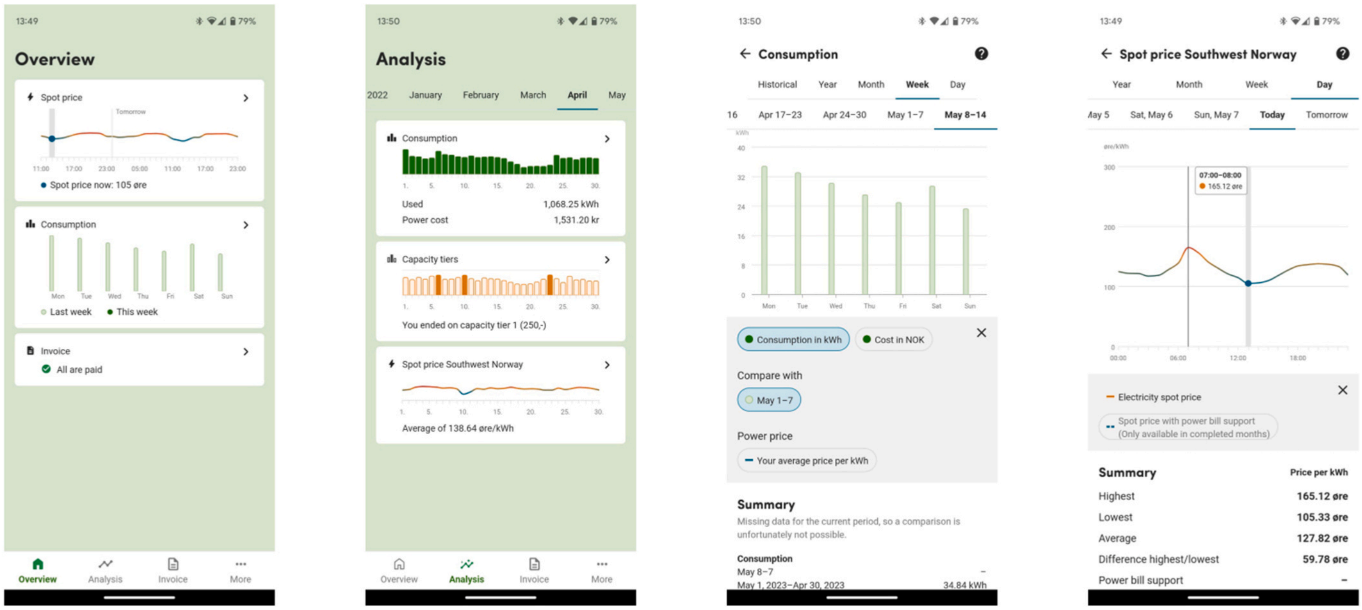

Fig. 4. Screenshots of Lyse energy app [82] – Used with permission.

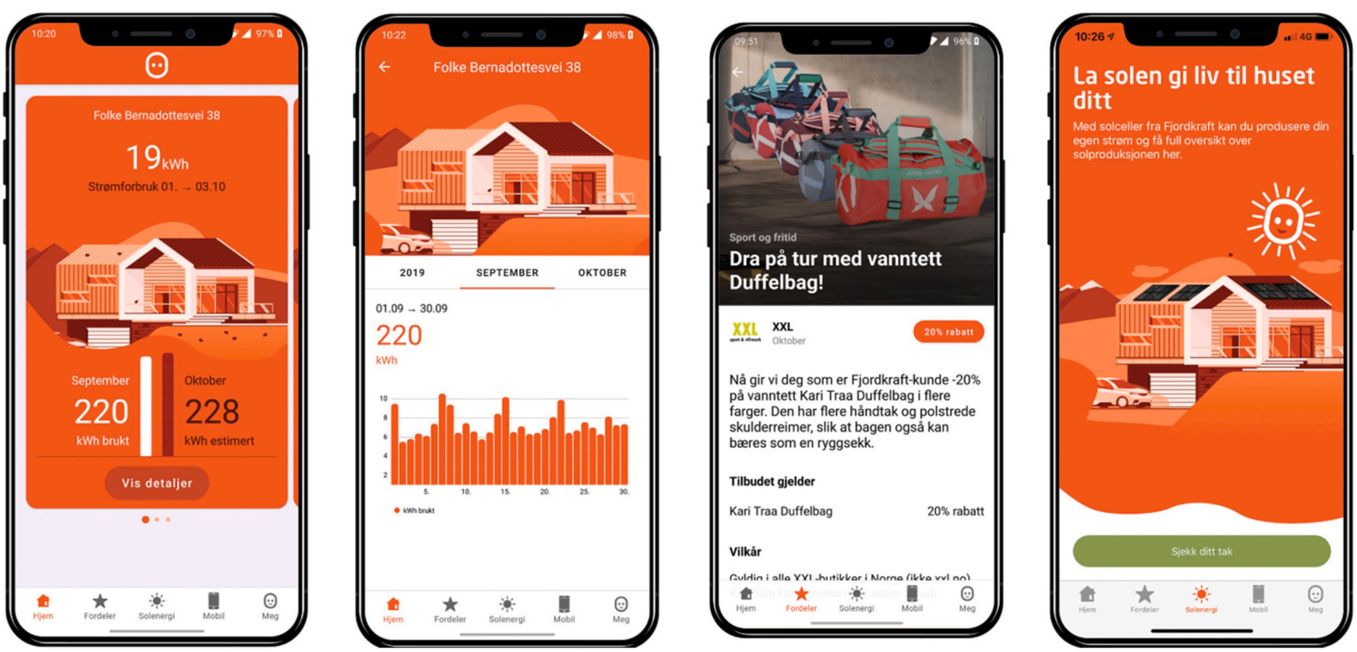

Fig. 5. Screenshots of Fjordkraft energy app adopted from Fjordkraft facebook page [91] – Used with permission.

consumption through a pilot study of 33 Norwegian households with in-home displays installed. The study reported that people's affluence and early experience with such smart solutions were important in their daily interactions. For the less affluent homes with no experience with displays, in-home displays can bring social benefits and energy savings. Nevertheless, they are unlikely to engage. Conversely, the affluent will not be forced to focus on saving money. The study is one of the few empirical studies on the smart digital solution based on direct feedback mechanisms in Norway. The on-demand useability, flexibility and other advantages of modern smartphone-based energy apps cannot be compared to a fixed home screen, so relevant empirical research is needed.

Since smart energy apps are free to use, they are available to anyone with a smartphone, no matter how wealthy they are. Moreover, the level of digitalisation, people's willingness to adopt sustainable practices and the growing energy challenges may mean that all population segments are willing to use smart energy apps to gain insight and control. This engagement will result in behavioural intervention in everyday energy practices.

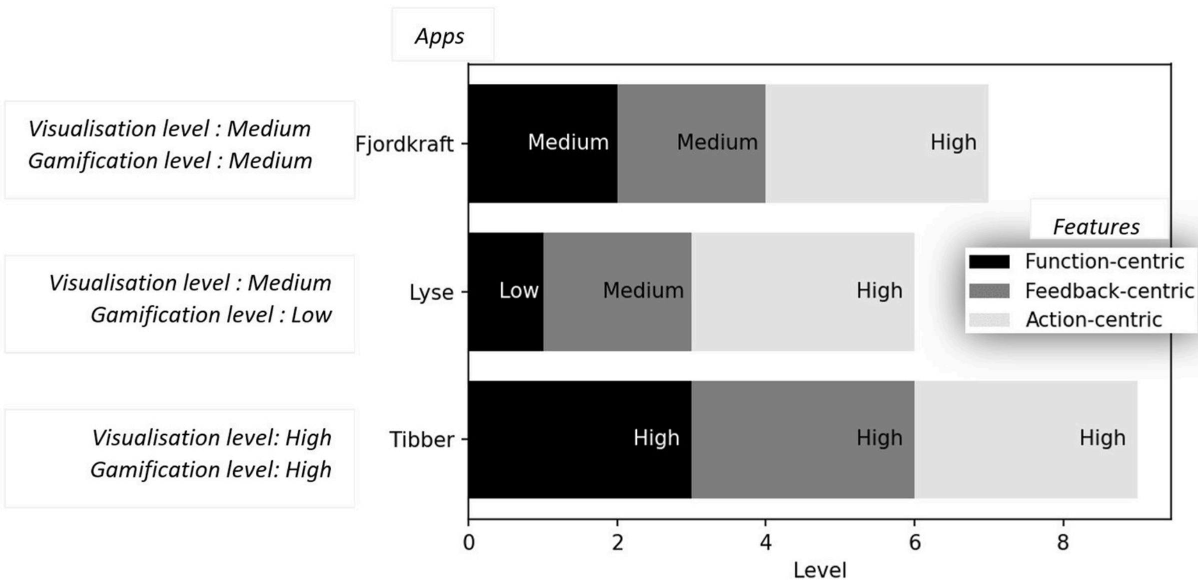

Fig. 6. Comparison of the three apps based on the level of features, visualisation, and gamification.

3.5. Commercial reports claim positive results on sustained behaviour change

Although there is no empirical evidence from academia regarding the positive results of smart energy apps in Norway, a few commercial reports claim that introducing energy apps has helped customers reduce their consumption. One such case study comes from Innlandskraft, an energy company with approx—240,000 customers across Norway and later in 2020, acquired by Fjordkraft (a leading utility) [75]. The case study reports a 6.8% reduction in average energy consumption after using an Eliq app. Based on a multi-year analysis of 1142 households in Norway, the report reviewed the smart meter data from 2013 before the app was introduced (2016–2018) and later compared it with the data after each user registered for the app until 2020. The results revealed that customers were more likely to use the app, with 71% reporting a reduction in their electricity consumption after starting to use the app, and an average customer reduced their electricity consumption each month from 1864 to 1757 kWh (6.8%).

Similarly, there is another report from Sweden where Eliq, the Swedish software provider in its webpage, reports their survey results among 1077 mobile app users powered by smart meter analytics over five years [71]. The effects on behaviour and purchasing habits related to energy are reported, which states that 95% of respondents said it had helped them better understand how they use energy, and 73% say it has directly enabled them to reduce their consumption. Furthermore, 91% said the app affected their behaviour, and 62% said it had directly compelled them to invest in reducing their consumption.

4. Discussions

The scope of this review was limited by the existing published research, which influenced the findings and conclusions. Furthermore, the analysis predominantly focuses on only three energy apps, despite a broader Norwegian market. This selection may introduce potential biases. To strengthen future research, it is recommended that a more comprehensive market is studied, utilising primary data to examine such apps' actual usage and influence. Additionally, conducting controlled experiments to comprehend causality is highly recommended. Moreover, exploring the possibilities of integrating smart energy apps with other smart energy technologies, such as home automation systems, be considered to understand the integrated potential to promote sustainable energy behaviours.

4.1. Research gaps

The findings show that several pilot projects and a wide range of studies have already looked into the impacts of various digital solutions on end-user behaviour and highlighted the potential of such solutions towards various behaviour changes. However, there is a research gap regarding using feedback-based smart energy apps as digital tools to promote desired behavioural change [16]. Geelen et al. [21] recommended further research on energy feedback based on smart energy apps to understand how they can guide citizens towards sustainable energy practices. Murugesan et al. [31] conducted a systematic review of digital feedback studies on residential energy behaviour change, highlighting that the number of studies utilising mobile phones (13%) and embedded displays (4%) was much lower than those using websites (72%). The authors note the growing popularity of mobile platform-based apps and suggest that research on digital feedback on energy use should focus more on mobile platform-based apps.

In the Norwegian context, research on app-based energy feedback is limited. Although there are some reports from the business side, their validity needs to be established through academic empirical studies. Unfortunately, even globally, most empirical studies are based on pilot studies rather than population-level apps and their impact.

Veskioja et al. [58] have pointed out the lack of research addressing how consumers are motivated to use smart energy services and substantiated this with data from Scopus, where no articles with the keywords "smart energy" and "consumer motivation" were found in June 2021. Similarly, a search conducted in Scopus in September 2022 with keywords "energy app*" and "behaviour change" yielded merely eight documents. This highlights the lack of proper literature and empirical evidence on the use and potential of smart energy apps as tools for digital energy behaviour intervention. Furthermore, there is insufficient understanding of citizens' perceptions, willingness, and motivations to adopt these solutions to further promote sustainable energy practices.

4.2. Policy implications

The use of smart energy apps has shown an unparalleled low-cost potential to intervene in the energy behaviour of urban domestic residents by providing feedback and encouraging them to adopt sustainable energy practices (for instance, adjusting heating systems, buying energy-efficient appliances, installing solar PV panels, smart management of EV charging, etc.). Moreover, energy apps are making the visibility of electricity more profound and easier to understand. As electricity prices reach record highs, people are more interested than ever in using these apps. In addition, the financial benefits of saving or managing residential energy consumption have incentivised users to use energy apps.

Analysing citizen engagement and energy practices based on interactions with smart energy apps has great potential for providing insights into behavioural dynamics. However, this potential has not been exploited to benefit the public and develop evidence-based policies.

The argument that saving energy is one of the easiest climate actions is often highlighted in the literature with added emphasis on adopting innovative digital solutions to help people to use energy smartly through the use of an app that provides insights and control to their energy use and ability to integrate various digital products to save energy. Using energy apps can also be seen as using technology to generate future value in a sustainable energy transition context. As argued by Gargiulo et al. [6], when the individual citizen is placed at the centre, innovation can be inclusive and easy to use and understand, which in turn can greatly influence the daily choices of individuals. The use of digital solutions may enable various actions, but their effectiveness depends largely on how humans interact with them to exploit the advantage they offer. Nevertheless, the advantages, such as cost saving, smartness, and on-demand feedback, help to make an informed decision on a collective level and certainly could shift towards a sustainable lifestyle and impact sustainable energy transition.

Norway's commitment to achieving carbon neutrality by 2050 depends on how the cities and the citizens' ability to respond to the decarbonization activities. As Norway has one of the highest per capita electricity consumptions, it is necessary to understand the innovative ways to develop and how the policymakers can use them to benefit the cities. Norway is one of the frontrunner countries to adopt digital advancements to enable citizens to exploit the advantage of energy visualisation and transparency [7]. The Norwegian context provides an opportunity to undertake empirical studies regarding energy apps and their ability to make behaviour-related changes to make sustainable impacts. The empirical findings from Norway may contribute to similar research in other countries and can guide the policymakers to implement such energy apps on the city level in other countries. In addition, the findings could be significant in making evidence-based policy formulations. Urban policymakers must understand the potential of these solutions that are not in the limelight but can contribute to the sustainable energy transition on the individual level. However, efficacy depends on individual preferences and the ability to constantly personalize feedback and intervene with individuals. Although the impacts on an individual level may be insignificant, the collective impacts would be significant.

5. Conclusion and further research

The relevance of sustainable residential energy behaviour is crucial to ensuring a sustainable energy transition. Moreover, the residential sector in Norway is progressive in adopting IoT sensors, smart energy meters, smart energy apps and other digital devices. Therefore, there is a great opportunity to combine digital technology with the human element, which can greatly accelerate the daily promotion of smart and sustainable energy behaviour.

Smart energy apps are a promising medium for digital feedback and offer great opportunities for shifting household energy behaviour that contributes to the sustainable energy transition on the individual level. Many Norwegian citizens are tech-savvy, and such apps are already being used on a population scale. Although commercial reports indicate the efficacy of such apps in fostering sustainable energy behaviour, there is a scarcity of academic studies that have attempted to understand technology-driven energy behaviour and the resulting behavioural change towards sustainable practices at a population scale. Policymakers should recognize and utilize the potential of such apps and the favourable Norwegian context to develop policies that promote increased adoption of such smart solutions and facilitate researchers for empirical studies. Additionally, the findings have significant implications for stakeholders to develop effective strategies for sustainable energy practices, emissions reduction, and climate change challenges while contributing to SDGs and encouraging future research on smart digital tools in different contexts and regions.

Future studies should focus on examining the influence of smart energy apps on individual behaviour change at a large-scale population level. Employing empirical evaluations will provide valuable insights into user motivations, perceptions, and the potential of these apps in promoting sustainable household energy choices. Norway's favourable context presents an ideal opportunity for such research. Moreover, the limitations and the potential biases arising from the scope of this analysis could be eliminated by exploring a broader market using primary data, conducting controlled experiments, and investigating the integration of smart energy apps with other technologies, such as home automation systems, which will be crucial in understanding their full potential in fostering smart energy behaviours. In addition, concerns such as inclusiveness, the digital divide, data privacy, negative spillovers and rebound effects may discourage the widespread adoption of such digital solutions. Further research within this field could explore these issues.

CRediT authorship contribution statement

Chandra Prakash Paneru: Conceptualization, Methodology, Resources, Writing – original draft, Project administration. **Ari K.M. Tarigan:** Writing – review & editing, Supervision.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

Acknowledgement

This study is supported by the Greencoin project, which has received funding from the "Applied Research – Cities for the future: services and solutions" programme (under grant agreement no. NOR/IdeaLab/GC/0003/2020–00). The project benefits from a grant from Iceland, Liechtenstein and Norway through the EEA Grants and the Polish budgetary funds. We would also like to extend our thanks to Tibber Norge AS, Lyse AS and Fjordkraft AS for generously granting us permission to use the images of their energy apps in this review.

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