Energy and Climate Change 6 (2025) 100225

Contents lists available at ScienceDirect

Energy and Climate Change

journal homepage: www.sciencedirect.com/journal/energy-and-climate-change

End-users' capabilities and futures in the Dutch energy transition: the role of data-driven energy technology in social housing

Kyra de Korte [a,b,*], Sietske Veenman [a], Maria Kaufmann [a], Berber Pas [b,c,e], Bernard van Gastel [d], Arnoud Lagendijk [a]

[a] Department of Geography, Planning and Environment, Institute for Management Research
[b] Interdisciplinary Hub for Digitalization and Society, Radboud University, Nijmegen, the Netherlands
[c] Institute for Management Research, School of Management, Radboud University, Nijmegen, the Netherlands
[d] Institute for Computing and Information Sciences Radboud University Nijmegen, the Netherlands
[e] Strict ICT Consulting, Vianen, the Netherlands

ARTICLE INFO

Keywords:
Capabilty approach
Future studies
Energy literacy
Data-driven energy technology
Social housing
Tenants

ABSTRACT

Data-driven energy technologies (DDET) are often framed as a panacea that will support the transition towards energy-neutrality by adjusting residents' energy practices. However, not all citizens seem to benefit equally from these technologies. To unpack how DDET influences citizens' capability to live a valuable life, we combine insights from the capability approach and future studies, addressing the following research question: *"How does the use of DDET influence public renters' capabilities, and what role do energy literacy and future expectations play in this relationship?"* This research employs a qualitative approach, with two Dutch case studies: Public Renters of Net Zero-Energy Homes (NZEHs) and public renters in less energy-efficient homes provided with energy displays by their housing corporation. We used in-depth interviews and observations. The results underscore the necessity for a holistic, practice-based perspective on the energy transition, which takes on board end-users' perspectives on desirable futures. Technological solutions can only work effectively if they are accompanied by recognition and support of public renters' capabilities. Energy literacy is a crucial factor in how individuals use resources like DDET to achieve capabilities such as energy management and financial stability. Limited energy literacy, restricts meaningful resource use, creating stress and missed opportunities. Strong energy literacy can enable renters to anticipate multiple future scenarios, and enhance their quality of life.

1. Introduction

1.1. Context

The Netherlands, like numerous other countries, faces the necessity of an energy transition (ET) to move away from fossil fuels. An important way to achieve the ambitions outlined in the Dutch Climate Agreement [1] regarding housing is by enhancing energy efficiency within the social rental sector. Data is seen a crucial tool for achieving efficiency [2,3]. As a result, many of the new devices being introduced in the energy sector rely heavily on or generate data themselves. We consider these devices Data Driven Energy Technologies (DDET).

There is a strong narrative that DDET are essential for enhancing peoples' capability to contribute to the energy transition (ET) [4,5]. DDET facilitates the exchange of information and communication about energy within a household. DDET intervenes in the distribution, production, and consumption of energy [6–8]. Characteristic aspects within the use of this data-driven technology are, among other things, a focus on energy efficiency for sustainability purposes, whereby DDET contributes to energy and cost savings by optimizing energy generation and consumption [8,9]. Concrete examples or types of DDET are smart meters, which provide real-time data on energy consumption and help users monitor their usage patterns, and home automation technologies such as smart thermostats, which adjust heating and cooling based on occupancy and preferences. Additionally, DDET includes renewable energy solutions like solar panel systems integrated with data analytics to maximize energy production and storage [10]. Data collected and transmitted in DDET is required for the device to function, for quality of operation or for invoicing to work.

However, technology alone cannot drive change [11], and it can also

* Corresponding author at: Radboud University Nijmegen, P.O. Box 9108, 6500 HK Nijmegen, The Netherlands.
E-mail address: kyra.dekorte@ru.nl (K. de Korte).

https://doi.org/10.1016/j.egycc.2025.100225

Available online 23 November 2025

reproduce injustice, as a strong focus on technological solutions may result in insufficient consideration of the challenges faced by vulnerable social groups in relation to DDET. Research has shown that social, economic, and technological factors can contribute to inequalities in access to, and utilization of, these technologies [12,13]. Empirical research is needed to ensure that DDET implementation is supported by evidence and considers the experiences of those most affected, particularly vulnerable and low-income households in social housing [13,14].

One framework that can help analyze how DDET is used and what factors influence the capabilities of different groups of people (e.g. public tenants) is the Capability Approach (CA) [15,16]. The CA, initially developed by Sen [17] and further elaborated by Nussbaum [18], has increasingly been employed as a lens to study inequalities within the ET [19–21]. A capability is the potential of persons to utilize their means to achieve a valuable life, such as the ability to live in accordance with personal desires, to freely express opinions, beliefs, and ideas, or to maintain a healthy life [16]. This study explores empirically how DDET, as a form of means, may influence the capabilities of social housing tenants. Various factors can influence the use of DDET. Within CA, factors are identified that enable or hinder someone to convert their means into capabilities. These are known as *conversion factors* (see Fig. 1) and can include a person's social context, housing, literacy, but also a person's health and/or external conditions such as the impact of climate change [22].

Research using the CA often emphasizes literacy as a crucial social right and an indicator of inequality [23,24]. In the context of DDET, energy literacy (EL) is key, as it impacts individuals' capability to adopt efficient energy consumption behaviors [25] and effectively utilize energy-related resources and technologies [26]. EL research, especially related to DDET, often focuses on device-specific knowledge, like understanding appliance energy consumption [27,28]. However, EL extends to understanding the overall household energy infrastructure, including maintaining technologies like ventilation systems or heat pumps. This broader form of EL, also referred to as multifaceted EL [28], include in addition to device and technology EL, consideration for the financial aspects of energy conservation, the actions that residents can take to save energy (such as placing foil behind radiators) and the notion of the preceding processes leading to household energy consumption and their influence on a broader socioecological system [28]. For example, the smart meter could tell people that energy use is expensive now, but will be cheaper in a few hours, so people can decide to use the energy later.

In the example above, the anticipation of when to use energy is important. In general, the concept of future anticipation within the CA has been acknowledged [29,30] but needs more empirical substation. As ET is all about the future, it is a suitable case to extend the CA framework by explicitly using the concept of anticipation. From an ontological perspective the future cannot be accurately predicted or empirically studied based on historical trends or present investigation. Instead, it is perceived through anticipation, where models or images of the future inform present actions [31,32]. Identifying anticipatory processes is key because they inherently involve limitations, influencing what is considered important in the present and shape perceptions of possible actions [33].This anticipation process is a growing topic in research, encompassing all efforts concerning the future [34,35].

Recent research highlights that citizens' anticipation towards the future can be an important factor that affects their participation in sustainability initiatives [36], however, the processes on how futures shape the use of DDET remain under-researched. Furthermore, studies indicate that EL is important in supporting individuals to make choices that reflect their values, particularly in the context of sustainability and energy efficiency [37–39]. Empirical research combining future studies (FS) and the CA is scarce. Conversely, the CA is widely tested and used in empirical studies regarding the ET [19,21,40]. Hence, by integrating the concept of anticipation with CA, we can create a more comprehensive and inclusive framework to examine the process of how DDET shapes social housing tenants' capabilities in the ET. Our research question is thus: *"How does the use of DDET influence public renters' capabilities, and what role do energy literacy and future expectations play in this relationship?"*

To answer this question, we focus on the Dutch case, where recent rising energy costs pose a serious financial burden on poorer households, threatening a just ET [20,41]. Efforts to reduce gas dependency and improve energy efficiency include DDET use, particularly in the social housing sector, where energy-efficient housing and energy displays are being introduced [42,43]. Within the Dutch case, two cases were selected, in which DDET plays a central role: (1) Public tenants in Net Zero-Energy Homes (NZEHs), aiming to generate at least as much energy as the user needs annually through automation and sustainable technology [44], and (2) Public tenants in homes still reliant on gas, using an energy displays via the housing corporation to monitor and manage their consumption. As explained later under methods, this qualitative study involves a narrative approach and observations to encourage public renters to talk about, and show, the impact of DDET on their daily lives [45].

1.2. Future studies and the capability approach

'The kinds of aspirations we have influence the kinds of capabilities for which we strive' [46].

Futures studies (FS) has a long history of systematically exploring the future in a broad sense [47,48]. FS emerged as a research field in the

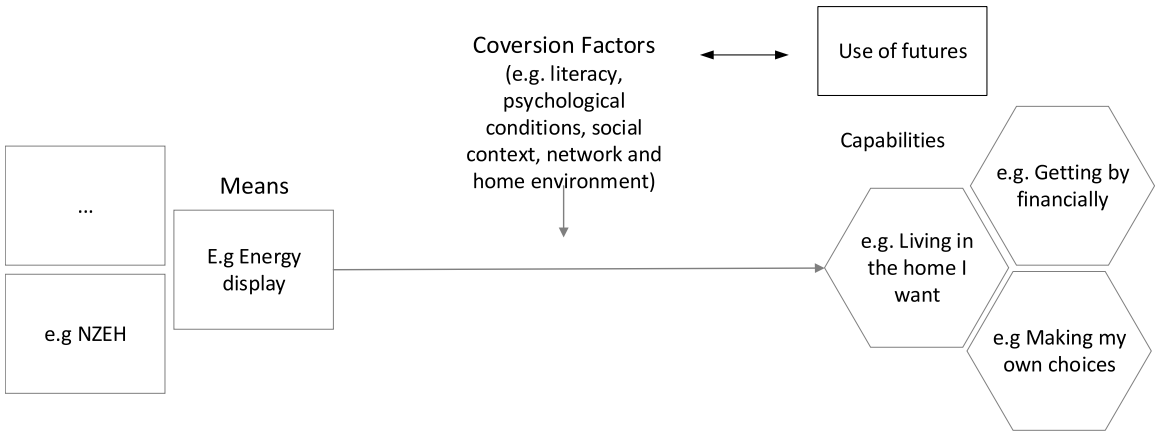

Fig. 1. The relationship between resources, conversion factors and capabilities, inspired by the work of Robeyns et al. [22] in The Capability Approach: An Interdisciplinary Introduction (p.12).

mid-20th century producing expertise for policy development and strategic planning. Particularly during the 1960s, there was a peak time for political planning due to dynamic changes in science, technology, and Keynesian economics [49,50] and the focus was mainly on forecasting and creating scenarios. Forecasting, or expected futures, are based on current trends and predictions, while scenario's, or probable futures, take into account more uncertain outcomes influenced by various factors [51]. This initial positivist orientation gradually shifted in the early 1970s, following growing criticism of technocratic planning. A more pragmatic and people-centered approach began to take hold, emphasizing ecological concerns, human values and the limits of purely technical solutions [49]. More recently, researchers in this area also refer to preferable futures, centered on the goals or visions of a future that societies or individuals hope to achieve [51] and critical futures, focusing also on the role of power and the performativity of futures.

Over time, FS have evolved to include new approaches, such as the concept of anticipation [52] and futures literacy [53]. Within anticipation, a distinction is made between the making of futures [51] and the use of futures [54]. The making of futures refers to action in the present, having consequences for how the future will look like. The use of futures is about the perspective on the future shapes the potential for taking action [33]. The future is used as an argument to do (or not do) something today [36,55]. Empirical findings of Veenman et al. [36] showed that reciprocal relationship between using and making of futures can be a mediating factor in people's abilities to (1) foreclosing futures; and, (2) pre-opening alternative futures [36]. For example, the fear of data breaches or concerns about a potential loss of autonomy (using the future) can discourage social renters from sharing their data and effectively utilizing an energy display via the smart meter (making the future) [56,57].

Regarding *using the future*, two types are typically distinguished [36]. First, *expected* futures represent a single vision of the future. Expected futures often project past and present trends into the future, implying a seamless continuation from the past and present to the future [58]. In essence, expected futures aim to depict a future without significant surprises [59]. The second type is *desired* futures, contrasting with expected futures by emphasizing normativity over neutrality. Desired futures seek to envision a singular desirable future (utopia) and then works backward to determine the steps needed to achieve it [60].

Several scholars have explored how FS and the CA can complement each other [29,30,46]. Poli [30] has taken the initiative to explore in various ways how the CA can intersect with FS by making the future orientation, which is a constitutive aspect of the CA, explicit. Poli [30] highlights the perspective that a person has options to live a valuable life [30,61]. This perspective can be seen as a 'developing agent' [30] that anticipates certain valued actions and states of being [30,62]. For instance, a person who wants to live in a sustainable public home with DDET can anticipate this by exploring the available options, registering early with the housing association, and staying informed about new developments regarding sustainability and DDET. All these steps are forms of anticipation of a valued capability, namely "living the way I want".

The capability to imagine and anticipate futures is known as futures literacy (FL). Future literacy presents a valuable addition to the CA [29,30], as it may enhance individuals' ability to imagine the future, much like literacy has expanded communication skills [30]. An important aspect is that people are capable of having aspirations [46]. Aspirations are twofold: they refer to the importance of the freedom that individuals enjoy in forming their aims, as well as to the opportunities to translate these desired futures into capabilities. It is important to understand how the environment in which people live shapes and constrains their aspirations, and how those aspirations in turn influence the development of their capabilities. Hart [46] talks explicitly about the capability to aspire, highlighting the fact that aspirations are often shaped by unequal power dynamics, which compel individuals to conform to perceived standards of normalcy and societal acceptance.

It should be noted, moreover, that the use of futures (expected and desired futures, aspirations) often occurs implicitly. People are often unaware that they are anticipating different futures [63]. The question arises as to how EL influences this implicit anticipation, especially since envisioning desirable futures is strongly shaped by an individual's social context [36]. To put it simply, if you are not aware of the opportunities for sustainability and energy savings, or have no idea how you can contribute to them, this will have an irrevocable impact on how you imagine different futures.

The role and use of shaping desired futures for individuals depends on a series of 'conversion factors' [20,46]. These conversion factors involve the interplay of personal traits, values, access to resources, and forms of capital [36,46]. Accordingly, the use of futures is interesting to examine not only from someone's capability (like being future literate), but also from the conversion factors that lead to someone's capability (Fig. 1), for example, the factors that influence the effective use of an energy display for the capability of getting by financially.

In what follows we will elaborate on the methodology of this research (Section 2), the empirical findings (Section 3), and discuss and conclude our findings (Section 4).

2. Methods

2.1. Case description

DDET can be a costly investment for residents, and in the public rented sector it is therefore not feasible for everyone to have this technology in their home. This study focuses specifically on the target group that encountered DDET through the housing association, where DDET was either provided for free or was built into the existing social housing. To cover as much of this group as possible, two different cases were selected.

The first case study focused on tenants in NZEHs in the province of Gelderland, the Netherlands. Here, senior residents live in energy-efficient buildings equipped with technologies like solar panels, heat pumps, and advanced insulation. The homes feature a simple energy display that provides information about the system's operational status, including temperature settings and modes, current water flow temperature, room temperature, and active heating mode. Additionally, residents have access to an app that offers real-time feedback on energy consumption and production. The homes are monitored for preventive maintenance.

The second case study examined tenants in North Holland and Gelderland living in homes still reliant on gas, many of which are drafty and slated for demolition or renovation. These tenants, burdened by high gas prices, use energy displays to monitor and manage their consumption. The displays provide (near) real-time usage data with a maximum delay of 10 s for electricity and 5 min for gas. They also offer daily consumption comparisons, helping tenants reduce energy costs. The studies were carried out in 2023.

2.2. Approach to data gathering and analysis

For the selection of public renters, we followed a typical case sampling approach [64] focusing on tenants who were able to use DDET through their housing corporation. This is an atypical situation for public renters, especially in the context of NZEHs, where such technologies are not yet widely adopted. For the first case, seventeen respondents were approached through the housing corporation, of which ten agreed to participate in the study. In some cases, the respondents' partners also joined the interviews. In the second case, we applied snowball sampling [65] by contacting five respondents via two energy coaches, who referred participants based on their familiarity with DDET. Additionally, two respondents were recruited through the housing corporation.

To ensure data saturation for both cases, we continued conducting

interviews until no new insights emerged. After several interviews, we noticed the same topics coming up repeatedly, indicating that additional interviews would likely yield redundant information. Furthermore, we aimed for maximum variation sampling by including respondents from different housing conditions (second case study) and a variety of social backgrounds, including factors such as gender and migration background. This helped capture a broad spectrum of perspectives, reducing selection bias and enhancing concept validity [66].

We used a narrative approach using Elicitation Techniques [67] in order to grasp the stories of public renters who use DDET. Elicitation Techniques are techniques that can help make interviews for the respondent easier by shifting the focus from abstract concepts (e.g. capabilities) onto external prompts. In this case we used a card set (Fig. 2) of 20 cards with sentences and pictures that are based on ten central capabilities [18]. In "Creating Capabilities," Nussbaum outlines that these central capabilities are meant as general objectives, which can be specified based on social and cultural contexts. These objectives were used by social work practitioners at the local welfare organization Bindkracht10 in Nijmegen and social work researchers from HAN University of Applied Sciences to develop the twenty Capability Cards [68,69].

First, we conducted open-ended interviews with housing corporation representatives, energy coaches, and experts to gain insights into the implementation and impact of DDET in various housing conditions. Afterwards, we interviewed the tenants, using the cards to encourage them to share what they value in their housing situation and the role DDET plays. The cards provided a structured framework while allowing freedom to articulate personal experiences and perspectives. The stories of these respondents provide a rich, in-depth understanding of their surroundings, and justify their actions and the meaning renters assign to their experiences [35,70]. We analyzed how the use of DDET aligns with personal life goals, meaningful activities, and capabilities, gaining in-depth insights into participants' experiences and perceptions of their housing situations.

Furthermore, we gathered data through observations [45] to grasp how DDET shapes the capabilities of public tenants. These observations consisted of pointing out and explaining the DDET in the home, and a demonstration of how they use it. Photos and videos were taken and attached to the interviews. We thus gained a full picture of the handling of DDET in the household.

We assessed participants' self-perception of EL applying the fourfold focus of van den Broek et al. [28] on (1) examining the practical application of DDET (Technology EL), (2) financial considerations related to energy conservation (Financial EL), (3) actions taken to conserve energy and ability to judge impact (e.g. Action EL), and (4) General energy knowledge and understanding of broader socio-ecological impacts (Multifaceted EL) [28]. Transcripts and observation notes were coded to identify themes related to knowledge, attitudes, skills, and behavioral changes regarding EL. The level of EL varied sufficiently to create three descriptive groups of social renters. Below, we present our findings by categorizing EL into three levels: poor, average, and high.

3. Results

3.1. Poor EL

Six social renters indicated how difficult it was to handle DDET, often because they had little knowledge of how to use DDET in their homes. This was evident not only from the interviews but also from observations. This group includes both public renters living in an NZEH and renters who received an energy display from the housing corporation. This group of respondents had a (very) limited view of the financial impact of the use of energy.

Low EL led in all cases to less effective use of DDET compared to the other interviewees. Depending on contextual factors, this limited EL led to (partially) undermining their capabilities when using DDET. Effective use of DDET in this context can be understood as the ability to fully utilize the energy display to make informed decisions, such as adjusting energy consumption patterns based on real-time feedback. EL also includes understanding how to adjust systems such as ventilation to increase user comfort while ensuring good air circulation.

This subsection presents the cases of Aïcha and Anton, social tenants provided with an energy display by the housing corporation, and subsequently the case of Jan and Annie, public renters residing in an NZEH.

3.1.1. Aïcha, 45–55 years, public renter with an energy display

Aïcha lives with her husband Amar and their children in a small rental home in Amsterdam. During the interview, accompanied by an energy coach, it becomes clear that her situation makes it hard to use the conversation cards. Aïcha is stressed and worried, dealing with financial difficulties. She tries to save energy but mentions that her energy display doesn't show gas usage, and her energy costs remain high. She mostly watches the electricity meter and frequently reminds her daughter to avoid using the hairdryer because it consumes too much energy.

"My daughter always uses those hair tongs, I regularly say put that thing away, it takes energy." -*Aïcha*

Conversations with multiple tenants from the second case study reveal that they often only pay attention to the moving meter on their energy display. By accessing the 'overview' function through the menu,

Fig. 2. The Capability Cards used by an end-user of DDET.

users can see the total consumption so far that day. This often provides a better understanding of the remaining capacity. However, this requires a certain level of EL from the user.

The energy coach suspects that the high bills are mainly due to gas consumption, which Aïcha cannot monitor. Upon checking, it shows that they only have a smart electricity meter, not a smart gas meter. Aïcha's husband had rejected a smart gas meter out of fear of higher costs, based on something he heard from a friend. Aïcha's limited EL, and that of her husband, hinders their ability to manage their energy consumption when using DDET. Her husband's fear of spending more money on energy has resulted in them having only a smart electricity meter, limiting their capability for managing finances with the help of DDET. So, an undesired future of her husband foreclosed a future deemed valuable, because they could have in managed their energy usage and reducing stress for the whole family. Now, Aïcha struggles to read the display properly, limiting her ability to understand her usage beyond the moment. Using DDET makes her uncertain and restricts her capability to use energy.

3.1.2. Anton, 55–65 years, public renter with an energy display

Anton, like Aïcha, has limited knowledge of the energy display. When he boiled the water with the kettle, the energy display showed high energy usage. So, Anton now boils his water on gas. During the interview he tells how he saw the meter running every time he used energy, and he expected to save money by not using energy. Anticipating this expectation, he decided to turn off the heating for most of the year, even on colder days.

"Initially, I lowered the temperature setting, but I did not feel much difference between the lowered temperature or completely turning it off. Therefore, I keep it turned off most of the time" - *Anton*

The energy coach who helped him with the energy display, is trying to get the neighborhood interested in a project where everyone goes off gas, but Anton doesn't want to get involved. He worries that energy usages become more expensive, and he questions if it is really necessary to change his practices. He has a lot of questions about the entire ET and the reasons for climate change. He doesn't believe much of what they say about climate change. So, he is not anticipating to move away from gas.

The energy display has contributed to Anton's capability to save energy and save money, which he values. He has been able to convert his means, both material (showerhead, appliances using gas, water, light) and non-material (social capital in the form of the energy coach), into a more energy-efficient living environment where he saves money. But Anton's limited EL means that he sometimes doesn't quite know how to best economize and he has difficulty dosing. Consequently, he makes very decisive choices (never use the kettle and completely shutting off the heating): he's sure he's saving at least. But he is less capable of *using* energy. He also doesn't immediately see the possibilities of going off gas. So, he doesn't use this future either. In short, his limited EL means that he can only take limited steps in the ET and faces the future with uncertainty, which leads him to extrapolate this uncertainty and anticipate an undesirable future, namely losing money by using energy. This leads him to foreclose the possibility of using energy.

3.1.3. Jan and Annie, aged 70–80, public renters of an NZEH

Low EL when using DDET doesn't always negatively affect people's capabilities. A strong social network and adequate resources can make a significant difference. Jan and Annie moved from a larger house with a gas connection to a single-store NZEH. Like other residents, they initially lacked knowledge about their new home. Soon after they moved in, COVID-19 cancelled the planned information session.

Jan, who has Alzheimer's, relies on Annie as his carer. She expressed concerns about managing financially, especially with increased laundry due to her husband's incontinence. Annie wanted a dryer but hesitated because of energy costs, not realizing how the energy efficiency of the home could help. Although their home has a display and app for monitoring energy use, she doesn't utilize these tools.

"My son says, 'Mom, looking at the energy usage, you can easily add a dryer. You don't have to worry about it.' I am afraid that I'll exceed the electricity limit. But apparently, that's not the case." *–Annie*

Annie now feels more financially secure, largely thanks to her son, who explained the flexibility of their energy use and the benefit of the solar panels. Despite this, she still occasionally worries about using energy. With more EL, she could benefit even more from DDET, monitoring what she consumes and feed back to the grid. Being less energy literate makes Annie feel uncertain and this often results in expecting a future where she can't pay the energy bills. Her son prevents her from anticipating this undesired future and helps her to invest in the care she needs.

3.2. Average EL

This group includes four public tenants who are reasonably comfortable with their energy display or NZEH. However, they sometimes lack the knowledge and skills to make the best use of the DDET. Typical of this is the story of Jacob and Susan.

3.2.1. Jacob and Susan, aged 70–80, public renters of an NZEH

Jacob and Susan have lived in one of the first NZEHs in the Netherlands for six years. Their house is older than others in the study, and the sustainable technology is housed in a poorly maintained shed outside. During the interview, Jacob and Susan demonstrate the installation, but they are unsure of the specifics. Jacob recalls that the filters, essential to the system, went untouched for three years before he replaced them.

"You should see how dirty it is inside. Never cleaned, never cleaned… But we had it for three years, in the beginning, nothing was done to it, nothing." – *Jacob*

Despite these issues, they are happy with their home, enjoying the large garden and convenience of the layout. Jacob is well-informed about solar panel policy and suspects the net metering scheme will soon change, predicting that energy feed-in might eventually incur charges, as with banks charging for savings deposits. Less than a year after this interview, energy companies begin charging for feed-in.

Jacob is optimistic saying: "My father used to say about new technology it'll never work… but everything turned out fine, and this (the house and the energy supply) will too." However, he stays actively involved, voicing his opinions through the residents' committee, ensuring they can rely on the housing corporation. The story of Jacob and Susan shows that DDET in their NZEH increases their capability to manage financially and live the life they want. But this is also due to the fact that they can rely on Jacob's capability to express his opinion. In the end, staying informed via the housing corporation leads to the use of a desired future that everything will turn out fine, pre-opening the capability to enjoy life.

3.3. High EL

This group includes seven end users who have been shown to be energy literate in terms of energy saving and the use of DDET. In some cases, this leads to the capability to get by financially and/or to develop other valued skills, such as contributing to a sustainable world. but in some cases, this EL does not lead to greater security in getting by financially or in enjoying your home or life. This is because other conversion factors prevent this ability. Linda's story is typical.

3.3.1. Linda, age 20–25 years, public renter with an energy display

Linda, in her early twenties, lives alone in a poorly insulated house and works in elderly care. Due to frequent showers and washing work clothes, her energy costs are high. She signed up for an energy display to monitor her usage and save money but never received it. Someone from the housing corporation told her there's little she can do to reduce energy consumption in her current home, which is scheduled for

demolition next year. Although she's unsure where she will live, the housing corporation has promised her a new home.

Linda stresses about getting by financially but closely monitors her expenses through apps, including one from her energy company, which provides daily consumption data via her smart meter. While she doesn't have real-time feedback, the app estimates which appliances use the most energy, with the air conditioner being a significant contributor. Despite this, she doubts an energy display would change her habits.

"On the one hand, I think maybe good to look at this display. But I'm not going to be sitting in the heat. (…) And I'm not going to sit out in the cold when it's winter either, thinking oh I won't turn on the heating because otherwise I'll have to pay." – *Linda*

Still, due to her living situation and finances, balancing these choices remains a challenge. She does not believe that real-time visibility of her consumption via an energy meter will change her behavior significantly, as she considers other valued capabilities, such as spending her free time and enjoying life, to be important. Her EL provided her insights into her possibilities and let her choose to anticipate a future she desires most. However, due to her living situation and tight finances, choosing one capability comes at the expense of another.

3.3.2. Olga, aged 50–60 years, public renter with an energy display

Social renters often don't realize how the energy display can help them financially. This was true for Olga, who was initially reluctant to seek energy advice until Meike, a volunteer energy coach, offered her a free consultation.

"I thought I didn't need help. But she [Meike] said it's free… She explained everything about the energy display and installed it. She also placed foil behind the heating unit, which was very nice." – *Olga*

That winter, Olga replaced her lights and began checking the energy display daily, even adjusting her cooking habits, sometimes opting not to use the oven. Her energy savings allowed her to replace her refrigerator with a more efficient model, thanks to a subsidy.

However, despite her awareness of high gas costs, Olga prioritized other capabilities, such as caring for her godchild.

"Making a difference for others is important to me. I don't have children myself, but I'm the godmother of a seven-year-old daughter of friends, and when she comes, I don't want to have to pay too much attention to my energy consumption, like when I put her in the bath and use a lot of water." – *Olga*

Insight into her energy consumption due to her EL enabled Olga to explore other valued capabilities. When the energy coach came back to ask whether she wanted to participate in an initiative to move away from gas (like she did with Anton), Olga was enthusiastic. She figured it's also better for the environment. Olga explains about the project that extracts energy from the heat of a nearby canal. She admits it's a complicated process, but the energy coach has told her enough about it.

"Contributing to a sustainable world is important. Not just for me, but also for your children and my godchild (…) that's why I also save on my energy consumption." - *Olga*

Olga's EL and social network made her explore other desired futures where she can contribute to a sustainable world. Furthermore, it enhanced her capability to manage her energy practices. Letting her use a future where she can take care of her godchild.

3.3.3. Joke, age 50–60, public renter of an NZEH

Joke made a very conscious decision to live in an NZEH, placing herself on a waiting list for an apartment years ago. Her old home, with its large garden, became too much due to her age and illness. Joke has cancer, and the capabilities of getting the care that she needs, living the way she wants, and making her own choices are especially important to her.

"I thought very far ahead about how I want to live… I decide for myself the way I want to live. Not in a care home. I wanted a nice flat with all the facilities nearby. Well, it came true." – Joke

She likes the automation and sustainability of her new home and anticipated many things early on, even attending an information session before construction started. Unlike some other residents, she didn't miss important details due to the pandemic. For example, she learned that the ventilation system could make the air dry, so she brought plenty of plants to her home, which helped.

Joke is content with her NZEH, despite some initial issues with the solar panels and ventilation system, which took time to fix. She says that the technology in her home helps her to enjoy life, saying it gives her relief and fewer worries.

It's clear that EL and early anticipation of a desirable future have been determining factors in Joke's ability to utilize DDET to live as she wishes and enjoy life. Her EL has been enriched by actively staying informed through various news channels provided by the housing corporation. This ensures that she can enjoy technologies that control automatic processes in the house, from ventilation to self-generation of energy.

4. Conclusion and discussion

In this study, we explored how the use of DDET influences public renters' capabilities, and what role EL and future anticipation play in this relationship. We did this by looking at two case studies in the social housing sector in which DDET was used: Among public tenants of NZEHs and among public tenants who had received an energy display through the housing corporation. To see how DDET contributes to the capabilities of public tenants, we combined insights from the capability approach and future studies. Based on our findings, three conclusions can be drawn.

4.1. The impact of EL on the use of DDET

The case studies demonstrate that EL is a crucial conversion factor influencing how individuals can utilize DDET (means) to achieve their desired capabilities (functions), such as managing energy consumption, living according to their preferences, and maintaining financial stability. This aligns with existing literature, which suggests that EL helps individuals make choices that reflect their values, particularly in the context of sustainability and energy efficiency [26,39]. For example, in Joke's case, where her EL has contributed to her feeling of control and comfort in her home, enhancing capabilities such as enjoying life. Conversely, a lack of EL can limit people's ability to use their resources (DDET) in meaningful ways. This was evident in Annie's case, where her limited understanding of EL caused stress. Similarly, Anton's minimal EL led to a narrow use of his display, viewing energy consumption solely in terms of cost, while overlooking the flexibility available for usage.

The CA allows for an analysis of how conversion factors influencing capabilities can interact to either reinforce or weaken one another. In Annie's case, her lack of EL was mitigated by a strong social network, as her son assisted her with financial decisions related to energy use. In contrast, despite Linda's EL, other factors—such as limited access to resources and her physical environment—restricted her ability to fully realize her capabilities, often forcing her to choose between competing capabilities. In Aïcha's case, we observed that her lack of EL exacerbated problems, as the use of DDET not only failed to alleviate her concerns but also increased her stress levels.

4.2. The relation between EL and the use of futures

This study shows that EL affects how individuals engage with futures. People like Aïcha and Anton, who have limited EL, expect a future that they fear: one in which energy consumption contributes to their financial inability to make ends meet. Their lack of knowledge and uncertainty regarding energy use led them to foreclose futures, such as using energy to meet their basic needs without fear of financial setbacks. This constrains their freedom to realize the capabilities they value, such as financial stability and stress reduction.

In contrast, Olga and Jacob anticipate desirable futures. They use their EL and social networks to explore opportunities that contribute to sustainable development and an enhanced quality of life. They are able to envision and weigh multiple future scenarios, and this ability influences which capabilities they perceive as feasible and desirable, ultimately shaping the capabilities they pursue or realize. Similarly, in Linda's case, her EL enables her to consider different future possibilities. She values financial security but also recognizes that she has just enough financial flexibility to engage in social activities with friends, and she anticipates accordingly.

Joke's story illustrates that the use of desirable futures can also enhance EL. Joke anticipated and adapted to the features of her NZEH well in advance, where her desired future of living as she wished was anticipated. Her proactive approach, including attending information sessions and researching ventilation issues, enabled her to make informed decisions, like adding plants to improve air quality. As a result, her EL enhanced by using a desirable future has supported her in maintaining a lifestyle aligned with her personal values and health needs.

4.3. Context factors and anticipation

Several authors have highlighted that FS serves as a valuable complement or extension to the CA [29,30,46]. For instance, FL is viewed as a capability that enables individuals to articulate various reasons for engaging with the future [48]. Additionally, Hart [36] emphasized the critical role of individual freedom in shaping desired futures and the opportunities to transform these futures into capabilities. She argues that the capability to aspire is dependent on a person's social context, which is influenced by conversion factors such as an individual's characteristics, values, social environment, and cultural influences, as well as the physical setting, including its structures and institutions.

This dynamic is also reflected in the experiences of social housing tenants. The circumstances of Jacob and Susan illustrate this well; by staying informed and living in favorable conditions, they can anticipate desirable futures. In other words, they possess the individual capacities to envision multiple futures. Sometimes contextual factors help open a future, as was the case with Annie. In which her son made her realize that there was financial room on which Annie anticipated. In contrast, Aïcha's story, and to a lesser extent Anton's, highlights the opposite. Aïcha's limited EL, combined with her personal circumstances, restricts her ability to envision a desirable future. Individual knowledge and beliefs also contribute to Anton ruling out certain futures.

Contextual factors are thus highly determinant of the use of DDET and the extent to which this use contributes to people's capabilities. Bringing the capability approach in line with the concept of anticipation reveals the interaction between these contextual factors and the extent to which people implicitly anticipate (undesirable) futures. If we want people to anticipate a sustainable world, they must first be able to imagine it. They need space and knowledge to aspire. Technology can help with this, but without context it remains a technological solution, which in some cases can actually limit opportunities.

4.4. Limitations and further research

In this research, we adopted a typical case sampling approach for both case studies. In the first case study on NZEHs, this approach resulted in a particular focus on the attitudes and experiences of senior tenants (over the age of 50). While this provides valuable insights, the findings offer a partial view, as they reflect the perspectives of a specific demographic within a specific context. Follow-up research could broaden the scope by including a more diverse range of age groups in relation to experiences with DDET in NZEHs.

Building on these qualitative insights, future research could also adopt a quantitative approach, complementing the existing body of work that primarily emphasizes energy efficiency. Our findings suggest that, while efforts to reduce energy consumption are important, it is equally crucial to understand whether individuals feel capable of *using* energy when needed for instance, to adequately heat their homes. Including EL in FS could help reveal whether tools like energy displays unintentionally lead to overly restrictive behaviors, rather than supporting informed and balanced energy use.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Kyra de Korte: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Sietske Veenman:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Maria Kaufmann:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Berber Pas:** Writing – review & editing, Supervision, Conceptualization. **Bernard van Gastel:** Writing – review & editing, Supervision, Conceptualization. **Arnoud Lagendijk:** 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.

References

[1] Government of the Netherlands, Climate agreement. https://www.government.nl/documents/reports/2019/06/28/climate-agreement, 2019.
[2] World Economic Forum, Power of digitalization: how better use of data is helping drive the energy transition, 01-10-2023 [cited 2024 07-22-2024]; Available from: https://www.weforum.org/agenda/2023/01/davos23-data-is-helping-to-drive-the-energy-transition/, 2023.
[3] G. Aruta, et al., Optimizing the energy transition of social housing to renewable nearly zero-energy community: the goal of sustainability, Energy Build. 282 (2023) 112798.
[4] IEA, Tracking Clean Energy Progress 2023, Editor, I.E. Agency, Paris, 2023.
[5] L. Cao, et al., Digital technologies for net-zero energy transition: a preliminary study, Carbon Neutrality 2 (1) (2023) 7.
[6] T. Ahmad, D. Zhang, Using the Internet of Things in Smart Energy Systems and Networks, 68, Sustainable Cities and Society, 2021 102783.
[7] G. Lobaccaro, S. Carlucci, E. Löfström, A review of systems and technologies for smart homes and smart grids, Energies. (Basel) 9 (5) (2016) 348.
[8] H. Lund, P.A. Østergaard, D. Connolly, B.V. Mathiesen, Smart energy and smart energy systems, Energy 137 (2017) 556–565.
[9] S.K. Mohapatra, S. Mishra, H.K. Tripathy, A. Alkhayyat, A sustainable data-driven energy consumption assessment model for building infrastructures in resource constraint environment, Sustain. Energy Technol. Assess. 53 (2022) 102697.
[10] F. Ahsan, et al., Data-driven next-generation smart grid towards sustainable energy evolution: techniques and technology review, Protect. Control Modern Power Syst. 8 (3) (2023) 1–42.
[11] A. Čavoški, The European green deal and technological determinism, Environm. Law Rev. 24 (3) (2022) 201–213.
[12] K. Bickerstaff, G. Walker, H. Bulkeley, Introduction: making sense of energy justice, Energy Justice Chang. Climate (2013) 1–13.
[13] S. Carley, D.M. Konisky, The justice and equity implications of the clean energy transition, Nat. Energy 5 (8) (2020) 569–577.
[14] W. Broers, et al., Justice in social housing: towards a people-centred energy renovation process, Energy Res. Soc. Sci. 88 (2022) 102527.
[15] I. Oosterlaken, Design for development: a capability approach, Design Issues 25 (4) (2009) 91–102.
[16] I. Robeyns, Wellbeing, Freedom and Social justice: The capability Approach Re-Examined, Open Book Publishers, 2017.
[17] A. Sen, Development As Freedom, Oxford University Press, Oxford, 1999.
[18] M.C. Nussbaum, Creating capabilities: The human Development Approach, Harvard University Press, 2011.
[19] R. Hillerbrand, C. Milchram, J. Schippl, Using the Capability Approach as a normative perspective on energy justice: insights from two case studies on digitalisation in the energy sector, J. Human. Dev. Capabil. 22 (2) (2021) 336–359.
[20] M. Kaufmann, S. Veenman, S. Haarbosch, E. Jansen, How policy instruments reproduce energy vulnerability-A qualitative study of Dutch household energy efficiency measures, Energy Res. Soc. Sci. 103 (2023) 103206.

[21] A. Melin, R. Day, K.E. Jenkins, Energy justice and the capability approach—Introduction to the special issue, J. Human. Dev. Capabil. 22 (2) (2021) 185–196.
[22] I. Robeyns, The capability approach: an interdisciplinary introduction, in: Training course preceding the third international conference on the capability approach, Pavia, Italy, 2003.
[23] B. Maddox, What good is literacy? Insights and implications of the capabilities approach, J. Human Develop. 9 (2) (2008) 185–206.
[24] M.C. Nussbaum, Frontiers of justice: disability, nationality, species membership. Frontiers of Justice, Harvard University Press, 2007.
[25] M. Seyedrezaei, B. Becerik-Gerber, T.J. Kohut, Exploring energy consumption in energy-efficient, affordable housing in Southern California: behavioral insights and financial implications, Energy Build. (2025) 115369.
[26] O.S. Santillán, K.G. Cedano, Energy Literacy: a systematic review of the Scientific literature, Energies. (Basel) 16 (21) (2023) 7235.
[27] T. Schwartz, et al., Cultivating energy literacy: results from a longitudinal living lab study of a home energy management system, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2013.
[28] K.L. van den Broek, Household energy literacy: a critical review and a conceptual typology, Energy Res. Soc. Sci. 57 (2019) 101256.
[29] R. Miller, Futures literacy, Media literacy and the capability approach to freedom, in: S. Ratajski (Ed.), Media Education as a Challenge, Editor, Polish National Commission for UNESCO: Warszawa, 2019, pp. 47–56.
[30] R. Poli, The implicit future orientation of the capability approach, Futures. 71 (2015) 105–113.
[31] R. Poli, R. Poli, *Introducing Anticipation*, in *Handbook of anticipation: Theoretical and Applied Aspects of the Use of Future in Decision Making*, Editor, Springer, Trento, Italy, 2019.
[32] R. Miller, R. Poli, P. Rossel, The discipline of anticipation: foundations for futures literacy 1. Transforming the Future, Routledge, 2018, pp. 51–65.
[33] K. Facer, A. Sriprakash, Provincialising futures literacy: a caution against codification, Futures. 133 (2021) 102807.
[34] R. Poli, An introduction to the ontology of anticipation, Futures. 42 (7) (2010) 769–776.
[35] S. Veenman, V. Kusters, P. Beckers, Exploring anticipated futures: dutch Grassroot Initiatives anticipating futures in the energy transition, Futures. 132 (2021) 102797.
[36] S. Veenman, M. Kaufmann, S. Haarbosch, Futures in the present: unraveling foreclosing and pre-opening desired futures in the local environment with a Bourdieusian perspective, Futures. 149 (2023) 103134.
[37] D.R. Cotton, et al., Developing students' energy literacy in higher education, Int. J. Sustainabil. Higher Educ. 16 (4) (2015) 456–473.
[38] J. DeWaters, S. Powers, F. Bilow, An introductory energy course to promote broad energy education for undergraduate engineering students, Sustainability. 13 (17) (2021) 9693.
[39] A. Martins, M. Madaleno, M.F. Dias, Energy literacy: what is out there to know? Energy Reports 6 (2020) 454–459.
[40] V. Pellicer-Sifres, N. Simcock, A. Boni, Understanding the multiple harms of energy poverty through Nussbaum's theory of central capabilities, Local. Environ. 26 (8) (2021) 1026–1042.
[41] P. Mulder, F.Dalla Longa, K. Straver, Energy poverty in the Netherlands at the national and local level: a multi-dimensional spatial analysis, Energy Res. Soc. Sci. 96 (2023) 102892.
[42] AEDES, Slimmer met je energie: huurders besparen met energiedisplay [cited 2024 08-03-2024]; Available from: https://aedes.nl/verduurzaming/slimmer-met-je-energie-huurders-besparen-met-energiedisplay, 2023.
[43] IEA, Energy system of The Netherlands, 22-07-2024]; Available from: https://www.iea.org/countries/the-netherlands, 2023.
[44] Woonbond, Nul-op-de-meter en EPV, 05-07-2024]; Available from: https://www.woonbond.nl/thema/goed-en-veilig-wonen/nom-woning-en-epv/, 2022.
[45] M. Angrosino, J. Rosenberg, Observations on observation, Sage Handb. Qualitat. Res. 4 (2011) 467–478.
[46] C.S. Hart, How do aspirations matter? J. Human. Dev. Capabil. 17 (3) (2016) 324–341.
[47] B. Adam, Wendell Bell and the sociology of the future: challenges past, present and future, Futures. 43 (6) (2011) 590–595.
[48] Z. Sardar, Future: All that Matters, John Murray, 2013.
[49] E. Seefried, Steering the future. The emergence of "Western" futures research and its production of expertise, 1950s to early 1970s, Europ. J. Futures Res. 2 (2014) 1–12.
[50] M. Godhe, L. Goode, Critical future studies-A thematic introduction, Culture Unbound 10 (2) (2018) 151–162.
[51] S. Inayatullah, From'who am I?'to 'when am I?': framing the shape and time of the future, Futures. 25 (3) (1993) 235–253.
[52] R. Poli, Introduction to Anticipation Studies, 1, Springer, 2017.
[53] R. Miller, Learning, the future, and complexity. An essay on the emergence of futures literacy, Eur. J. Educ. 50 (4) (2015) 513–523.
[54] L. Mayo, S. Veenman, M. Kaufmann, Making and using futures: using anticipation to reframe justice and responsibility to govern societal transformations, World Futures. (2024) 1–24.
[55] J. Beckert, Imagined futures: fictional expectations in the economy, Theory. Soc. 42 (2013) 219–240.
[56] S. Hielscher, B.K. Sovacool, Contested smart and low-carbon energy futures: media discourses of smart meters in the United Kingdom, J. Clean. Prod. 195 (2018) 978–990.
[57] T. Sharon, When digital health meets digital capitalism, how many common goods are at stake? Big. Data Soc. 5 (2) (2018) 2053951718819032.
[58] H. Nowotny, Insatiable curiosity: Innovation in a Fragile Future, MIT Press, 2010.
[59] M. Van Asselt, F. van der Molen, A. Faas, S. Veenman, Uit zicht: Toekomstverkennen Met Beleid, 24, Amsterdam University Press, 2010.
[60] S.W. Haarbosch, M. Kaufmann, S. Veenman, A Mismatch in Future narratives? A comparative Analysis Between Energy Futures in Policy and of Citizens, 3, Frontiers in Sustainable Cities, 2021 654162.
[61] S. Alkire, S. Deneulin, *The Human Development and Cability Approach*, in *An Introduction to the Human Development and Capability Approach Freedom and Agency*, London, Sterling, 2009, p. 351.
[62] I. Robeyns, The capability approach: a theoretical survey, J. Human Develop. 6 (1) (2005) 93–117.
[63] C. Selin, The sociology of the future: tracing stories of technology and time, Sociol. Compass. 2 (6) (2008) 1878–1895.
[64] B. Flyvbjerg, Five misunderstandings about case-study research, Qualitat. Inquiry 12 (2) (2006) 219–245.
[65] P. Biernacki, D. Waldorf, Snowball sampling: problems and techniques of chain referral sampling, Sociol. Methods Res. 10 (2) (1981) 141–163.
[66] R.K. Yin, Case Study research: Design and Methods, 5, Sage Publications, London, 2009.
[67] K.C. Barton, Elicitation techniques: getting people to talk about ideas they don't usually talk about, Theory Res. Soc. Educat. 43 (2) (2015) 179–205.
[68] A. Brummel, E. Jansen, M.A. Yerkes, J. Javornik, Potential for social innovation in social work: applying the capability approach, in: Social Work and Social Innovation, Policy Press, 2024, pp. 54–66.
[69] A. Brummel, F. Hendriks, H. Joosten, E. Jansen. *Capability Cards*, HAN., Nijmegen, 2024.
[70] S. Veland, et al., Narrative matters for sustainability: the transformative role of storytelling in realizing 1.5 C futures, Curr. Opin. Environ. Sustain. 31 (2018) 41–47.