Energy Policy 147 (2020) 111720

Contents lists available at ScienceDirect

Energy Policy

journal homepage: http://www.elsevier.com/locate/enpol

Designing for justice in electricity systems: A comparison of smart grid experiments in the Netherlands

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ARTICLE INFO

Keywords:
Energy justice
Design for justice
Smart grid systems
Digitalization
Flexibility
Case study research

ABSTRACT

In future urban energy systems, smart grid systems will be crucial for the integration of renewable energy. However, their deployment has moral implications, for example regarding data privacy, user autonomy, or distribution of responsibilities. 'Energy justice' is one of the most comprehensive frameworks to address these implications, but remains limited regarding smart grids, and regarding concrete guidelines for designers and policymakers. In this paper, we fill this gap by answering the following research question: How do design choices in smart grid projects impact energy justice? Thereby, four smart grid pilot projects are evaluated in a comparative qualitative case study research design. Data was collected through semi-structured interviews and a content analysis. Our findings contribute to the energy justice literature with insights regarding the design for distributive, recognition, and procedural justice. They underscore the importance of fairness in data governance, participatory design, user control and autonomy, technology inclusiveness, and the design for expansion and replication. Future research should explore the feasibility to govern smart grids as commons and the relationship between trust and perceptions of justice. We conclude with policy recommendations for funding future smart grid experiments and for facilitating the implementation of storage through electricity sector regulation.

1. Introduction

In the transition to low-carbon energy supply, urban electricity systems need to become more flexible (Muench et al., 2014; Powells and Fell, 2019; Verbong et al., 2013). Growing shares of intermittent renewables, especially from solar photovoltaic (PV) systems, increased electricity demand from electric vehicles, and the electrification of heat put pressure on urban electricity grids (Connor and Fitch-Roy, 2019). Smart grid systems respond to these challenges by applying advanced information technologies (IT) to bridge temporal gaps between electricity supply and demand. Technologies such as smart metering, storage, or home energy management systems (HEMS) also imply a more active role of electricity users. Consumers become prosumers,[1] can increase their self-consumption through the addition of storage, or offer batteries as flexibility resources to the grid (Goulden et al., 2014; Renström, 2019). Hence, consumer adoption is a prerequisite for smart grids to be successful.

However, the deployment of smart grids has moral implications which form barriers to the systems' adoption (Milchram et al., 2018b). For example, the reliance on real-time sharing of household data raises concerns regarding privacy violations (Cuijpers and Koops, 2013). Another example is increased automation in digital systems, which might result in reduced user autonomy while giving energy companies more control over households' electricity use (Michalec et al., 2019). Also, changing actor roles, e.g. the greater importance of software providers and more active roles of households, raise uncertainties regarding the distribution of responsibilities and risks (Connor and Fitch-Roy, 2019; Diestelmeier, 2019a).

Over the past ten years, 'energy justice' has been increasingly used as a framework to understand and address moral implications of energy

Abbreviations: DSO, distribution system operator; HEMS, home energy management systems; IT, information technology; P2P, peer-to-peer; PV, photovoltaic; TSO, transmission system operator.

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[1] Prosumers are defined as actors that are both producers and consumers of renewable energy (Kubli et al., 2018; Parag and Sovacool, 2016).

https://doi.org/10.1016/j.enpol.2020.111720
Received 30 January 2020; Received in revised form 22 June 2020; Accepted 24 June 2020
Available online 20 October 2020

decision-making, but justice concerns arising from an increased digitalization in electricity systems have not yet attracted much attention. Energy justice addresses the "equitable access to energy, the fair distribution of costs and benefits, and the right to participate in choosing whether and how energy systems will change" (Miller et al., 2013, p. 143). Drawing from environmental justice (Schlosberg, 2007), a three-dimensional understanding of 'justice' is dominant: distributive justice (addressing the allocation of benefits and harms), justice as recognition (giving attention to inclusiveness and potential misrecognition of vulnerable stakeholder groups), and procedural justice (concerned with equitable decision-making processes).

Milchram et al. (2018a) was among the first to conceptualize justice for the context of smart grid systems, raising attention to how smart grids might impact distributive and procedural justice. Additionally, some scholars have analyzed distributive implications of variable energy tariffs enabled by smart metering, which pose disadvantages for energy vulnerable populations. Low-income groups with low demand flexibility are the most adversely affected consumers, for example because peak hours may become too expensive for them (Neuteleers et al., 2017); they live in poor quality housing (McGann and Moss, 2010); they cannot afford flexibility technologies (e.g. batteries, smart appliances) and they spend a higher share of disposable income on energy costs compared to higher-income groups (Powells and Fell, 2019).

Whereas this literature is valuable for justice conceptualizations and understanding of distributive impacts of smart metering with variable tariffs, it offers little holistic insight into how energy justice can be achieved through smart grid design. This paper contributes such insight by analyzing how design features of implemented smart grid systems influence perceptions of distributive, recognition, and procedural justice. It aims to operationalize the three dimensions of energy justice, evaluate smart grid implementations, and develop design and policy recommendations for just and smart grids. Hence, the paper asks: How do design choices in smart grid projects impact energy justice? To address this question, we analyze the design of four implemented smart grid pilot projects in the Netherlands in a comparative case study research. Thereby, the paper contributes to making energy justice measurable so that existing technologies and their institutional embeddedness can be evaluated and compared with respect to their justice implications, enabling justice to become an (operationalized) design goal in smart grid systems.

The following section introduces smart grids and develops an evaluation framework, which forms the theoretical basis for the case comparison. Section 3 outlines the comparative case study research method and describes the empirical context of smart grids in the Netherlands as well as the four cases. Findings from the case comparison are discussed in Section 4. Section 5 outlines design implications and recommendations for policymakers.

2. Background

2.1. Smart grids

In smart grids, information technology (IT) systems are used to bridge temporal gaps between the supply and demand of electricity. Due to the use of digital technologies and the reliance on the collection and sharing of real-time household energy generation and use data, the concept 'smart grid' is often used as an umbrella term for digitalization in the electricity network. Up to now, smart grids are mostly implemented in pilot projects, combining (some of) the sub-systems depicted in Fig. 1 (Geelen et al., 2013). In such systems, micro-generators, like for example PV or small wind turbines, generate electricity on household or community level. To match supply and demand, a range of flexibility-providing units can be applied (Eid, 2017). These are storage systems to use electricity at different times than it was produced or avoid the purchase of electricity from the grid during peak hours (Geelen et al., 2013); smart household appliances (e.g. heating/cooling systems, white goods), which automatically shift operation to times when renewable energy is available; or variable tariffs, which incentivize consumers to shift their electricity use to times when renewable supply is available or away from times of peak demand (Warren, 2014). Smart metering provides (near) real-time information on electricity supply, distribution, demand, and storage, and bidirectional communication of data to and from end users (Warren, 2014). This is needed for monitoring and control systems to visualize electricity flows. Home energy management systems (HEMS) and their user interfaces (e.g. in-home displays, apps, web portals) provide end-users information on electricity flows and the possibility to steer their electricity use (Wilson et al., 2015).

2.2. Developing an evaluation framework for energy justice in smart grids

To compare the design of smart grid systems for their influence on energy justice, this section develops an evaluation framework, in which

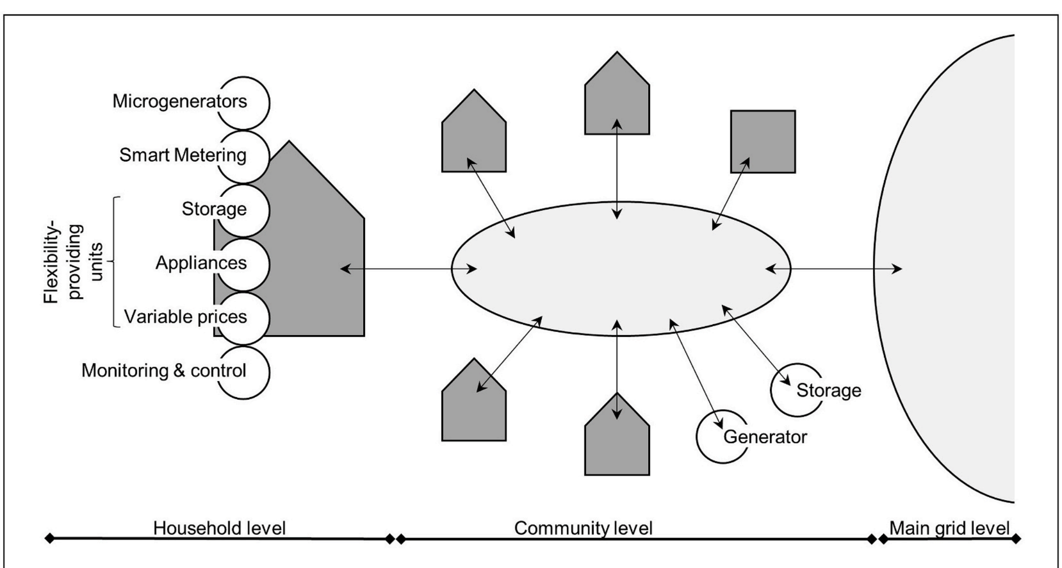

Fig. 1. Schematic overview of a smart grid system.
Source: adapted from Geelen et al. (2013).

Table 1
Evaluation framework for energy justice in smart grids.

Justice Evaluation Criteria	Definition (Perceived justice of …)
Distributive	
Distribution of profits	… profit division among participating households
Distribution of costs	… cost distribution among participating households
Public funding	… financing smart grid pilots with government subsidies or by distribution system operators
Knowledge sharing	… the availability of project learnings and results to the wider public
Data governance	… household data collection, storage, access, and use by project consortium
Recognition	
Selection of community	… the process to choose a neighborhood for the project
Selection of participants	… participation criteria for households
Technology accessibility	… usability and inclusiveness for diverse user groups
IT literacy required	… IT knowledge required to use the systems
Procedural	
Household participation (general)	… user inclusion in decision-making processes
Household participation (data)	… user inclusion in decision-making on data governance
Control vs. automation	… the extent to which households can control the system vs. how much is automated
Transparency (general system)	Potential for households to comprehend effect of their behavior on electricity use
Transparency (data)	Potential for households to understand who has access to their data and how

the three dimensions of energy justice (Jenkins et al., 2016) are operationalized into more concrete and context-specific evaluation criteria (Table 1). The evaluation framework includes aspects that are highlighted in existing conceptualizations of energy justice (e.g. Jenkins et al., 2016; McCauley et al., 2013; Schlosberg, 2007) and draws to a great extent from a review of (potential) injustices associated with smart grid systems in Milchram et al. (2018a).

2.2.1. *Evaluation criteria for distributive justice*

Distributive justice is the equitable distribution of benefits and harms among stakeholders affected by energy systems (Walker, 2009). Evaluation criteria therefore focus on the objects of distribution: *What* are benefits and harms to be distributed? (Sovacool and Dworkin, 2015).

The first two criteria are the *distribution of profits and costs* between smart grid users, which might have implications for the affordability of energy. The need to ensure that lower income households do not spend a disproportionally larger share of their income on energy services compared to higher income groups is an important topic in energy transition research (Miller et al., 2013). Unfair cost distributions result for example from smart metering and variable tariffs when lower income groups with a low flexibility to shift their energy use are adversely affected (Powells and Fell, 2019).

A second monetary criterion is the *perceived justice in public funding of smart grid pilots*. EU-wide, national governments and/or the European Commission co-fund 85% of those projects. In the Netherlands, these two sources make up 41% of the total investment (Gangale et al., 2017). We also consider financing by distribution system operators (DSOs) as public funding, because Dutch network operators are owned by national and regional governments (Mulder and Willems, 2019).

Additionally, we evaluate *the extent to which knowledge gained in a smart grid pilot project is shared with the wider public*. Smart grid projects are implemented to gain experience how the technologies impact the grid, develop new business models, and ultimately to learn for future large-scale offering of such services (Gangale et al., 2017).

We also include the *perceived justice in the collection and use of household data*. Smart grid services rely on real-time household energy generation and consumption data. Hence, consumers do not only pay money, they also ‘pay’ with their data, similar to data becoming increasingly important as a currency to pay for services in a digitized society (Kool et al., 2017).

2.2.2. *Evaluation criteria for justice as recognition*

Justice as recognition addresses the inclusiveness of energy systems, especially for vulnerable stakeholder groups (Schlosberg, 2007). The guiding question here is *who* is (not) affected by a system and if there is equitable recognition of vulnerabilities.

Important design choices are firstly the *selection of the community* and the *selection of households*, which will have implications for generalizing learnings beyond the pilot project context (Milchram et al., 2018a).

In addition, our framework assesses the *accessibility and inclusiveness of the system*. We ask to what extent the technologies applied in a smart grid are accessible in a fair way to different user groups (e.g. high and low income households, house owners and tenants). Smart grids have been criticized for their lack of accessibility in particular to lower-income populations, tenants, and elderly and disabled people (Milchram et al., 2018a; Powells and Fell, 2019). Whereas these accessibility issues constitute inequalities, at first glance they do not seem to be an issue of injustice. Novel technologies usually need investment by higher income early adopters for prices to decrease over time, thereby increasing accessibility (Rogers, 2003). In energy systems, however, socialization of electricity network costs and subsidies for renewables mean that higher income groups with suitable houses, who are able to install PV, can benefit by saving energy costs. Lower income households, who cannot afford their own generation, might face rising energy bills from increased implementation of renewables (Chapman et al., 2016).

Attention has also been raised to varying degrees of *IT literacy* as a factor for exclusion in smart grids systems (Buchanan et al., 2016). In a survey of smart grid projects targeted at social housing tenants, Gangale and Mengolini (2019) find that low technological skills represent serious challenges for such projects. Therefore, we include a separate criterion on the IT literacy required for participation.

2.2.3. *Evaluation criteria for procedural justice*

Procedural justice focuses on equitable decision-making procedures (McCauley et al., 2013). The guiding question is thus the *how* of decision-making, with focus on the *meaningful participation* of the local community and the *transparency* of such procedures (Boudet, 2019).

Regarding participation, we evaluate the mechanism through which households are *included in decision-making* regarding system design and the collection and use of household data. Participatory decision-making has a significantly positive impact on the adoption of smart metering and related services (Guerreiro et al., 2015). Yet, research has criticized lacking user participation and engagement in smart metering rollouts and smart grid experiments (Gangale and Mengolini, 2019; Sovacool et al., 2017).

We also assess how the system itself allows *user participation and control relative to the degree of automation*. Smart grids can allow users to take a more active role in controlling their electricity use (Geelen et al., 2013). Yet, the application of complex digital technologies also requires expertise and the involvement of software providers and aggregators,

Table 2
Overview of interviews and interviewees.

Case	Interviews	Interviewees
Virtual Power Plant (Amsterdam)	N = 11	DSO (2x) Energy supplier/Aggregator (1x) Software provider (1x) Research institute (1x) Municipality representative (1x) Participating households (5x)
Community Battery (Rijsenhout)	N = 4	DSO (2x) Local energy supplier (1x) Participating household (1x)
Local Energy Market (Hoog Dalem)	N = 7	DSO (2x) Hardware provider (2x) Consulting (1x) Participating household (2x)
Gridflex (Heeten)	N = 11	DSO (2x) Energy cooperative (1x) Hardware provider (1x) Software provider (1x) Aggregator (1x) Consulting (3x) Participating households (2x)

potentially shifting power away from users and raising the concern of losing autonomy to IT systems (Milchram et al., 2018a).

Regarding *transparency*, the framework considers to what extent the HEMS user interface enables users to understand the causality between their energy-related behavior and their electricity use (and consequently their bill). How households receive feedback regarding energy use, generation, and system functioning matters for procedural justice, because the information is a key enabler for capitalizing on demand flexibility (Powells and Fell, 2019).

Additionally we include a criterion on the extent to which households have *transparency over the collection and use of their energy-related data*. Although smart grids have the opportunity to make energy more visible, the functioning of IT systems, algorithms, and the way they use data are often opaque for users (Kloppenburg and Boekelo, 2019).

3. Methodology

Since smart grids are to date mostly implemented as pilot projects (Gangale et al., 2017) and an analysis of how design influence energy justice requires in-depth and real-world context-dependent knowledge, a qualitative comparative case study research design was chosen (Flyvbjerg, 2006; Yin, 2014). Four smart grid pilot projects in the Netherlands served as cases: A virtual power plant in Amsterdam (subsequently abbreviated as VPP), a community battery storage pilot in Rijsenhout (CBS), a local energy market in Hoog Dalem (LEM), and the project 'Gridflex' in Heeten (GF). Selection aimed at 'maximum variation cases' (Flyvbjerg, 2006): VPP was chosen as a typical smart grid case, led and developed by a DSO, and implemented in a top-down fashion. CBS was chosen because it works with social housing tenants, LEM because it was started on household initiative, and GF because it is led by an energy cooperative under a legal exemption. Additionally, projects had to be implemented in or after 2017 to ensure use of the system and possibility for project stakeholders to recollect their experiences. Selection was also guided by accessibility of interviewees and documents.

3.1. Data collection and analysis

Data was collected through 33 semi-structured interviews and a content analysis of project documents. We interviewed people who were directly involved in the design, implementation, and use of the system (Table 2). Interviewees were recruited based on purposive and snowball sampling. This limits generalizability but is in line with our overall qualitative approach and the aim to study in-depth how and why design choices are evaluated as (un)fair (Yin, 2014). The main aim of the interviews was to evaluate the cases' design with respect to justice. Interviews had two parts (see Appendix A): firstly, the interviewee's role in the project and a description of the system; secondly, the evaluations of justice. For justice evaluations, we operationalized the framework presented in Section 2 into interview questions. The questions were answered on a five-point scale, which either ranged from 'very unfair' to 'very fair'[2] or from 'very opaque' to 'very transparent'. Each closed question was followed by an open question to discuss the rationale for the quantitative rating and collect further information about the projects design choices. Interviews were conducted in English and Dutch between September 2018 and May 2019. They lasted between one and two hours, were recorded with the permission of the interviewees, and transcribed before the analysis.

Secondary data was used to confirm interview findings regarding the system design. The document analysis included the projects' (progress and final) reports, presentations given by project members, and news reports.

The interview transcripts and secondary material were analyzed with the qualitative and mixed-methods software MAXQDA. Quantitative analyses involve descriptive statistics and median comparisons of the evaluation criteria (Field, 2013). Qualitative analysis of open interview questions and project documents was done through inductive coding (Mayring, 2014). The coding was conducted by the first author. The co-authors performed an intercoder check.

3.2. Smart grid development in the Netherlands

In the Dutch energy transition, smart grids are attributed a special importance as an alternative to electricity network expansion. The share of electricity demand from renewable sources – 18% in 2019 with the majority from wind and solar energy – is forecasted to grow substantially in the next ten years in order to reach 2030 emission targets (Afman and Rooijers, 2017; CBS, 2020). At the same time, however, renewable energy developers have already faced difficulties in connecting wind and solar parks to the electricity grid, due to lacking, insufficient, and ageing infrastructure (Ekker and van de Wiel, 2019).

The Dutch government incentivized experimentation with smart grid pilots, the majority of which have taken place in low-voltage residential areas. Most pilot projects are initiated and led by the DSOs (Cambini et al., 2016). Initially only focusing on the demonstration of new technologies, the government also fosters legal experimentation since creating the 'Experimentation Decree' in 2015 (Ministerie van Economische Zaken, 2015). It grants energy cooperatives exemptions from the strict ownership unbundling in the Dutch Electricity Act.[3] They are thereby not only allowed to own renewable generation, but also supply their members directly with electricity, operate the part of the distribution grid belonging to the project, and determine their own network tariffs (Diestelmeier, 2019b). Although still small in number, cooperative smart grid initiatives are rising as a result (hier opgewekt, 2019).

Recently, smart grid pilots are also motivated by the expected phase-out of net metering for residential prosumers from 2023 onwards (Directoraat-generaal Klimaat en Energie, 2019a). With net metering,

[2] The adjective 'fair' is chosen here instead of 'just', because several pilot interviews indicated that interviewees were unfamiliar with 'just' and found 'fair' more comprehensible. As a consequence, this paper uses 'fair' and 'just' interchangeably, although we acknowledge that justice is more encompassing than fairness.

[3] The Dutch electricity market is characterized by full ownership unbundling. Commercial activities (generation, trading, and retailing) are thus under separate ownership than network operation. Network ownership and operation are in the hands of one transmission system operator (TSO) and several distribution system operators (DSOs), which are owned by local and national governments (Mulder and Willems, 2019).

Table 3
Overview of smart grid set-up in the four cases.

	VPP	CBS	LEM	GF
Project Consortium Members and Responsibilities				
DSO	Alliander (project leader)	Alliander (project leader)	Stedin (project leader)	Enexis
Supplier	NeoSmart	Tegenstroom (perceived project leader by households)	–	–
Energy cooperative	–	–	–	Endona (project leader)
Aggregator	NeoSmart	–	–	University of Twente
Software Provider	EXE (an Alliander subsidiary), Sympower	Lyv Smart Living	iLeco	ICT group
Hardware Provider	-via Alliander	-via Alliander	ABB	Dr. Ten
Consultants	–	–	Energy.21 (development of Layered Energy System concept)	Escozon (supporting Endona); Enpuls (Enexis subsidiary supporting battery system); Buukracht (Enexis subsidiary; user engagement)
Project Participants				
Participating households	48 households (mostly owner-occupier)	35 households (social housing tenants, renting the solar panels)	16 households (owner-occupiers)	47 households (owner-occupiers)
Composition of the Smart Grid				
Microgenerators	Rooftop PV systems (all participating households)	Rooftop PV systems (all participating households)	Rooftop PV systems (subset of households)	Rooftop PV systems (50% of households)
Smart Metering	✓	✓	✓	✓
Flexibility-providing units	Home batteries (5 kWh, all participating households)	Community battery (128 kWh virtually distributed to the households, every household has access to 3 kWh)	3 home batteries (12 kWh); heat pumps (all households)	20 home batteries (5 kWh, sea salt batteries); variable network tariffs
Monitoring & Control System	VPP steering software (buy and sell electricity based on wholesale price, battery capacity, available solar power, and network load); Transaction platform (clearing and settlement of electricity deals); Online portal as HEMS (electricity use, generation, battery status);	Battery steering software; HEMS (electricity use, generation, battery status)	Local energy market software connected to consortium blockchain to register transactions between households; App as HEMS (electricity use, generation, battery status; allows trading)	Battery steering software; App as HEMS (electricity use, generation, status regarding the two pricing mechanisms)

the most beneficial option for prosumers is to feed excess electricity into the grid as they get exactly the same price per kWh feed-in as they pay for kWh use from the network (Huijben and Verbong, 2013). Consequently, there is no financial incentive for household storage to increase self-consumption. The replacement of net metering is expected to decrease this feed-in compensation and hence increase the financial viability and deployment of storage (Directoraat-generaal Klimaat en Energie, 2019a).

3.3. Case descriptions

The following section provides a description of the four cases. Table 3 gives an overview of their set-up.

3.3.1. Virtual power plant in Amsterdam (VPP)

The Virtual Power Plant (VPP) is located in Amsterdam Nieuw-West and part of a five-year European Union funded program to demonstrate technologies for energy efficient cities (City-zen, 2019). It is led by DSO Alliander. The capacity of home batteries is aggregated and the resulting flexibility is used for trading on the day-ahead wholesale market. The project ran from 2016 to April 2019, with the VPP operated in trading mode from April 2018 to March 2019. The aim of the pilot was to test storage systems, develop a business case for trading local flexibility on the wholesale market, and thereby give residential prosumers access to energy markets. 48 households participated, and all of them had owned PV systems before project start.

3.3.2. Community battery storage in Rijsenhout (CBS)

This community battery storage (CBS) was implemented in a suburban village close to Amsterdam, in cooperation between DSO Alliander and the municipal energy supplier Tegenstroom. Here, the excess solar generation of one neighborhood is stored in a community battery. The project ran from 2015 to 2018, and the battery was implemented in spring 2017 (Van Santen, 2017). The aim was to understand how a community battery can mitigate supply peaks and keep the voltage level in the local low-voltage grid stable. 35 social housing tenants, who rented PV systems, participated in the project.

3.3.3. Local energy market in Hoog Dalem (LEM)

The LEM case study is located in a new residential area and led by DSO Stedin. Previous to this project, a first smart grid pilot had been implemented in the area to test home batteries, smart household appliances, heat pumps, and PV (Stedin, 2019). LEM was initiated in 2017 by a group of households who had already participated in the first pilot and was ongoing at the time of data collection. Eventually, 16 home owners participated in LEM. The aim of the project is to maximize the use of electricity generated within a neighborhood by incentivizing households to trade electricity with each other (Energy.21 and Stedin, 2018). The project is the first implementation of the so-called 'Layered Energy System', a peer-to-peer trading (P2P) system that was developed by the DSO Stedin and the IT consultancy energy.21. In this system, transactions between households are registered in a consortium blockchain. Community electricity markets form the lowest level of the electricity system and have prices that are lower than the prices on the national market (Energy.21 and Stedin, 2018). At the time of data collection, home batteries and a beta-version of the app was available, in which households could trade electricity on a virtual market place, i.e. they could see monetary consequences of their trading in the app.

Table 4
Overview of results: Design choices influential for justice evaluations.

Justice Evaluation Criteria	Design choice decisive for justice evaluation	Influence on justice evaluations[a]
Distributive		
Distribution of profits	Individual vs. collective profit allocation	~
Distribution of costs	No additional cost for households	+
Public funding	Share of funding from public sources	+
Knowledge sharing	Extent of knowledge sharing with wider public and other projects	+
Data governance	Sharing of household data among project consortium; Anonymization	~
Recognition		
Selection of community	Structured selection process; Technical criteria for community selection	~
Selection of participants	Self-selection	~
Technology accessibility	Absence of requirement to own PV system and battery; Experimentation with social housing tenants	+
IT literacy required	High ease-of-use	+
Procedural		
Household participation (general)	Degree of user participation in project decisions	~
Household participation (data)	Degree of user participation in project decisions	~
Control vs. automation	Degree of household control	+
Transparency (general system)	Extent of information shown on user interface	+
Transparency (data)	Extent of user comprehension on data usage	+

[a] + … positive influence; ~ ambiguous influence (see text for details).

3.3.4. Gridflex in Heeten (GF)

GF is being implemented in a new residential area and led by energy cooperative Endona, a citizen-led local energy initiative. The system is a combination of battery storage, an energy management system, and variable electricity tariffs. 47 home owners participated. The project was started in 2017 and was ongoing at the time of data collection: the implementation of the batteries had just started and the variable tariffs had just been developed. The main aim of the project is to maximize the self-consumption of locally generated renewable electricity by individual households and by the neighborhood as a community in order to minimize the load on the neighborhood's transformer (Enexis, 2017).

GF experiments with variable network tariffs. This is unusual[4] and relevant for later justice evaluations. Experimenting with two mechanisms, the network tariff component of the household electricity bill is variable depending on the network load. The first pricing mechanism is a collective one in which the households pay a low/medium/high price depending on low/medium/high load on the neighborhood's transformer. The entire neighborhood load determines the network tariffs paid by the households. In the second pricing mechanism, a household's network tariff is based on its individual load. Network tariffs are higher at peak times than at off-peak times and cost is determined by the individual household load.

4. Results and discussion

The four pilot projects were evaluated and compared regarding perceptions of justice. The following section presents and discusses the results of the case comparison. First, we address results for the three justice dimensions separately. In Sections 4.2 and 4.3, we turn to more general discussions on design considerations arising from interrelations between the three dimensions and from justice implications that go beyond a single pilot project.

4.1. Case comparison: Evaluations of justice

This section discusses why certain design choices received higher justice evaluations than others. On average, on the five-point scales, many design choices were evaluated as somewhat or very fair. This may be traced back to a social desirability bias as interviewees had a tendency to give evaluations in line with what they thought would be socially preferred answers (Fisher, 1993). It is not problematic, however, because consistent with our qualitative research design, case comparisons were mainly based on the inductive analysis of reasoning behind justice evaluations. The descriptive quantitative ratings provided indications of potential differences in evaluations. The combination of both answer types gives valuable insights regarding a fair smart grid design, as the following paragraphs will show.

First, Table 4 gives an overview of the design choices that were decisive for justice evaluations as well as the direction of their influence. Appendix B contains the detailed description of relevant design choices in the four pilot projects.

Before discussing the detailed results in the following paragraphs, a comparison of evaluations for the three dimensions of justice reveals on average lower evaluations for recognition and procedural justice (Fig. 2). This indicates that lacking inclusiveness and participation are more challenging than distribution of benefits and harms. It can also be traced back to a general technology-oriented mindset that can be found in many smart grid projects (Hansen et al., 2020; Obinna et al., 2016). The testing of novel technologies is more in focus than social and moral aspects. This is also reflected in the projects' aims, and more strongly so for VPP and CBS than LEM and GF.

4.1.1. Evaluations of distributive justice

From the perspective of distributive justice, GF received the highest evaluations, followed by CBS, LEM, and VPP. Fig. 3 shows the results for all distributive evaluation criteria.

4.1.1.1. Distribution of profits and costs. Justice evaluations regarding the distribution of profits were dependent on the projects' choice for an individual or collective profit allocation mechanism. The comparison of VPP and GF is particularly interesting, because both were characterized by collective action situations (Ostrom, 2005): in VPP, the aggregated battery capacity is a common resource; in GF, a pricing mechanism incentivizes the community to keep their collective load as low as possible. Whereas VPP chose for an individual profit allocation, GF opted to allocate profits to the community as a collective.

In VPP, profits occurred through trading the aggregated battery

[4] The charging of dynamic network tariffs is made possible by the exemption from the current Dutch electricity law, which was granted to Endona under the Experimentation Decree (see also Section 3.2).

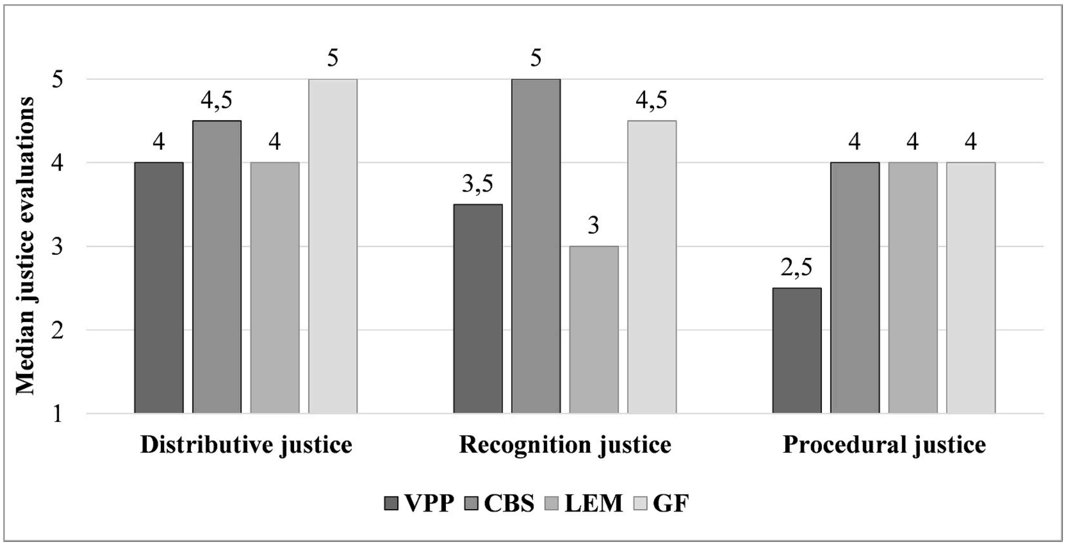

Fig. 2. Justice evaluations across cases.

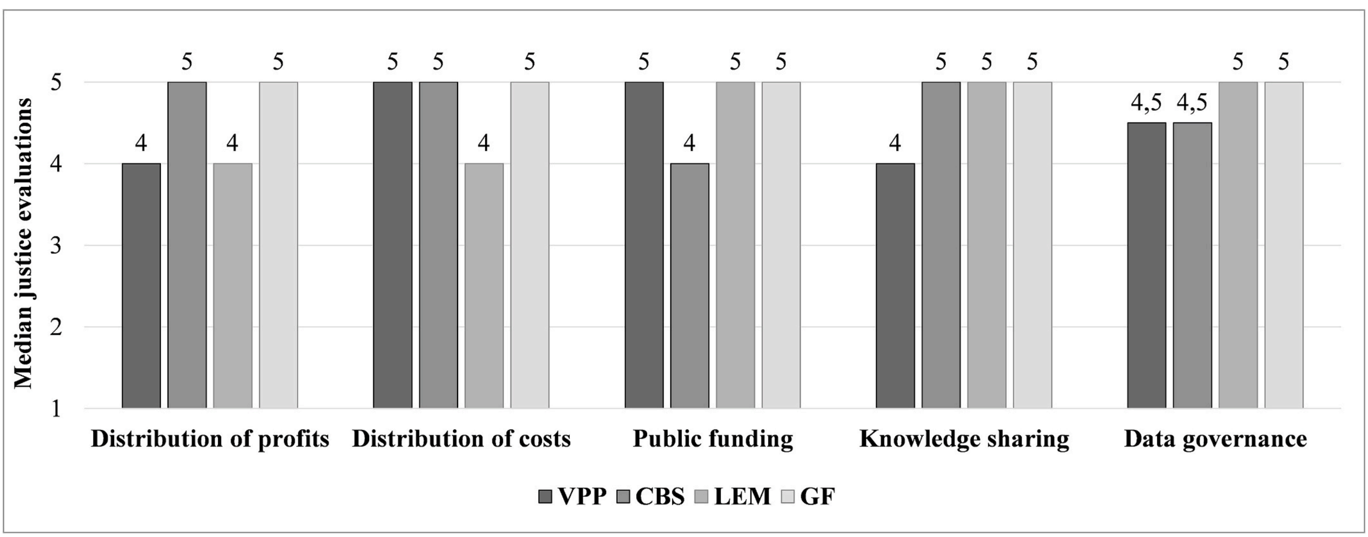

Fig. 3. Evaluations of distributive justice across cases.

capacity on the wholesale market. Profits were allocated equally to individual households.[5] The distribution principle was not evaluated as very fair, because households had no control over (dis)charging, the (dis)charging frequency was unequal, and this led to unequal increases in energy bills due to on average 34% battery losses. To remedy this problem, the project decided to compensate households for battery losses. This solution was acceptable in the pilot, but not realistic in a market setting. In a market setting, our interviews indicate that a model where suppliers/aggregators rent part of the battery for a fixed fee, leaving households to use the remaining capacity for self-consumption, would be acceptable for prosumers.

In GF, monetary benefits occurred if participating households shift their energy demand as incentivized by variable network tariffs. The collective mechanism – in which network tariffs vary depending on the load on the community's transformer (cf. section 3.3.4) – was perceived as more fair than the individual mechanism. It was considered less disruptive for households because they might benefit from solidarity in the community to shift demand. In the individual mechanism, any inability to shift peak demand would directly result in higher costs. Any profits that would occur through the variable tariffs are allocated to the community for a collective benefit, which was evaluated as fair and consistent with the collective process: a community effort to achieve energy savings should be rewarded by a collective benefit for the entire community. This reflected the understanding that not all households have the same ability to shift demand. Vulnerable groups with low demand flexibility might indeed be adversely affected from variable tariffs (Powells and Fell, 2019). The collective mechanism was a way to protect households from potential negative effects occurring in individual mechanisms.

Summarizing, findings indicate that individual profit allocation is appropriate if (a) individual households can control their benefits directly, (b) have transparency over their influence, and (c) there is no energy community. Collective allocation would be perceived as fair if (a) benefits depend on collective action, and (b) households are part of an

[5] This was the principle for distributing potential profits. In reality, at the end of the project no profits were made. Although the VPP succeeded in lowering electricity cost per kWh, due to the battery losses more electricity was used and had to be bought: on average 34%. As a result, the total cost of energy was €852 higher than it would have been without the batteries.

energy community who collects and disburses monetary gains.

From a theoretical perspective, high justice evaluations of the collective mechanism for variable tariffs and profit distribution suggest that governing local smart grids as commons can enable distributive justice. Governance as commons refers to the community-based governance of a shared resource in which outcomes are determined by collective effort and require community coordination (Euler, 2018; Ostrom, 2005). To make this successful, however, it is necessary to avoid that individuals rely on others in the community to keep the collective load stable rather than taking action themselves. Whereas some households might have legitimate reasons not to shift their demand (for example, due to sickness), others might free ride. To avoid this, smart grid designers might follow a set of governance principles, among which are participatory decision-making processes regarding system governance; monitoring of individual users' behavior by people who are accountable to the community; sanctions for users who violate collective rules; access to conflict-resolution mechanisms; and recognition of the community-governance by external governmental authorities (Ostrom, 2005).

4.1.1.2. Public funding and knowledge sharing. Evaluating justice regarding public funding and knowledge sharing, findings show a clear pattern across all cases: Public funding is justified if knowledge gained from the project is shared externally so that pilot projects deliver learnings for a future sustainable electricity system. Government subsidies are thereby considered necessary to incentivize innovation and small-scale experimentation with novel technologies. Once technologies and business models are judged feasible, market parties should implement solutions on a bigger scale.

Despite its importance and high justice evaluations, knowledge exchange with and from other projects is seen as challenging. First, in most smart grid projects aggregators or small energy suppliers develop and test proprietary business models. Interviewees recognized that public money is spent on private business model development, and that such insights are not shared widely by entrepreneurs. Second, interviewees highlighted that 'learning by doing' is more effective than 'learning by reading'. A better codification of learnings throughout the project through an explicit project role for documenting learnings, decisions, and ensuring accessibility to the public at the end of the project would improve knowledge sharing. In addition, knowledge exchange can be facilitated if members of past projects are involved, for example in the form of steering committees. It should include households who participated in similar projects and the DSO would be a suitable organization to organize and oversee such (a) committee(s).

4.1.1.3. Data governance. In all projects, smart metering data is used for automation and shared within the project consortium. This was evaluated as somewhat or very fair, under the conditions of anonymization, appropriate data protection, and data use that corresponded to the project purpose. Many interviewees did not judge data governance as an issue of fairness, indicating that smart grid systems are predominantly seen as energy systems rather than data-based systems. Household data were not considered to be part of the 'costs' households pay for the service. Households judged data collection and use as appropriate because they saw the nature of the projects as *research*. The involvement of public companies and universities spurred household trust and increased the perception that data were used in a fair way. These findings differ from justice in research on digital platforms and internet systems. There, consumers' privacy concerns are related to perceptions of distributive fairness (how benefits from data collection and use are distributed between consumers and firms who collect data) and procedural fairness (how respectfully consumers were treated in the process of data collection) (Ashworth and Free, 2006). This should also apply to the collection of personal data in smart grid systems. Based on this literature and our findings that trust in the involved public organizations was key to see data collection as appropriate, we might predict that the more the systems will be understood as data-driven systems, and the more they are offered as a market service, the more potential unfairness in data governance will become salient for users. Our findings indicate that services offered by cooperatives as well as the continued involvement of DSOs as public 'guardians of fairness' might have an advantage over market services offered by bigger 'untrusted' companies.

4.1.2. Evaluations of justice as recognition

With respect to justice as recognition, CBS received the highest evaluations, followed by GF, VPP, and LEM (Figs. 2 and 4).

4.1.2.1. Selection of community and participants. In all projects, the communities were selected without a wider process of screening for suitable places. In VPP, CBS, and GF, the selection was mainly done for technological reasons, which was considered as fair if that meant that the project could realize cost savings. In LEM, the fact that the project was initiated bottom-up by the participating households was seen critically because the community had already participated in (and benefitted from) a previous smart grid pilot. This confirms that bottom-up initiatives might not always be positively associated with enactment of justice (Breukers et al., 2017; Catney et al., 2014; Forman, 2017). Interviewees thus recommended a public selection process for future projects.

All cases used a self-selection process for participating households,

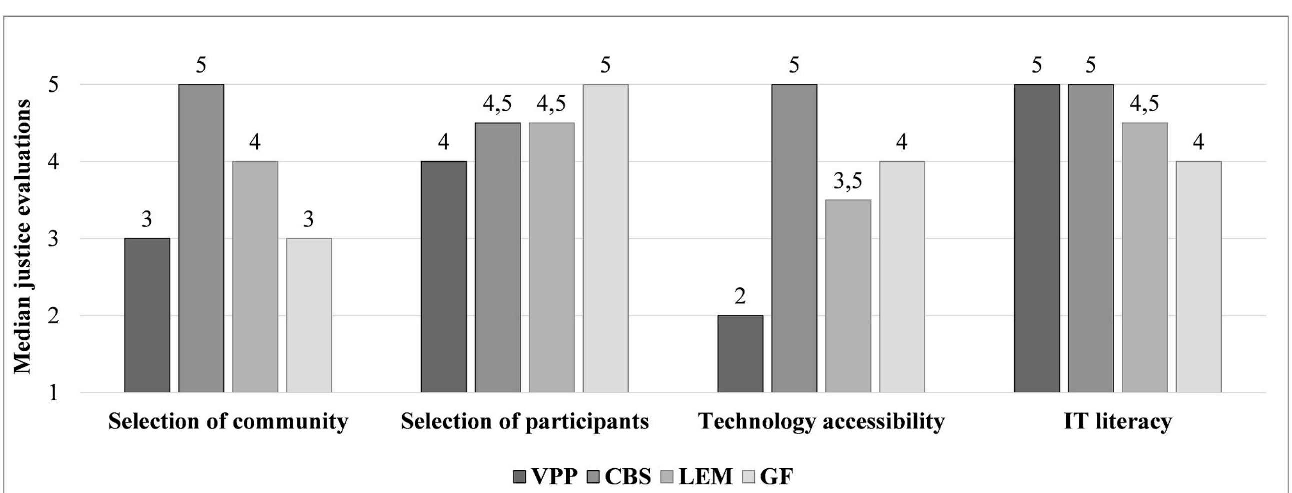

Fig. 4. Evaluations of justice as recognition across cases.

meaning that households signed up for the project. This is problematic for generalization and risks structural misrecognition of the needs of other – especially more vulnerable – groups in society. Participants in three out of four cases were home owners who were already interested in energy, and had invested in renewable generation or energy efficiency measures.

4.1.2.2. Accessibility. Justice evaluations of the accessibility of technologies in the four cases were dependent on whether participating households needed to own PV systems and/or batteries, reflecting the lacking inclusiveness of PV and storage systems due to requirements regarding income, space, and house ownership. These factors for exclusion often co-occur, e.g. for lower income households living in dense urban areas with little space as (social housing) tenants. Such households are at higher risk of energy poverty and disproportionally vulnerable to changes in the energy system (Gillard et al., 2017; Poruschi and Ambrey, 2018). Although interviewees acknowledged that income barriers are only problematic in a transition phase until PV and battery prices will fall further (Kalkbrenner, 2019), they also stressed that even in this transition phase, mechanisms to make the technologies already accessible for lower-income households are important as the systems enable energy and costs savings.

Our findings highlight such mechanisms. CBS, which was evaluated as the most inclusive, demonstrated the benefits of a community battery for tenants of a social housing association. The involvement of social housing tenants is rare as most smart grid pilot projects work with home owners due to relatively easier implementation (Lammers and Heldeweg, 2016). The combination of rented solar panels and the community battery increased the system's affordability and was seen as a good role model for future applications in social housing communities.

GF and LEM promote accessibility by not requiring households to own or install large technologies. Households only needed smart metering and HEMS, which were provided to them during the project. Additionally, GF offers a role model how energy cooperatives could set up a smart grid. Cooperatives are often regarded as a more inclusive governance mechanism for energy projects and smart city initiatives as they allow citizens direct participation in decision-making (Martin et al., 2018). Cooperative smart grid initiatives are rising in the Netherlands, but are still uncommon since such projects are technologically more complex than the dominant cooperative activities, namely setting up energy generation facilities (hier opgewekt, 2019). However, GF operates under the Experimentation Decree, is thus generally not in line with current electricity legislation and scaling-up would necessitate legal changes. LEM on the contrary would be easier to scale up, because it is congruent with the existing energy market, operating with open standards and protocols in order to enable services by all potential aggregators, software and hardware providers.

4.1.2.3. IT literacy. Across all projects, we found similar results with respect to the IT literacy required from users: Pilot systems were judged as easy to use; all potential users were IT literate enough, as the systems required only knowledge how to use a smartphone app or an online portal; and the lower the IT knowledge required from the users, the more inclusive and accessible the system would be. These opinions were particularly held by consortium members, whereas several households mentioned that the user interface should have been simpler, a discrepancy that highlights the importance of user-centric design.

In addition, our findings show that the projects attracted people who are interested in new technologies. Such a self-selection bias raises again questions how insightful findings are for future scaling-up. It also means that the potential for exclusion might not lie in the actual IT knowledge required to use interfaces, but more in the perceived complexity, lacking knowledge about the opportunities of home automation, and little interest in such systems that prevents people from even considering adoption. Hence, lacking knowledge of and about such systems might be a greater barrier for inclusiveness than the knowledge needed to operate them.

4.1.3. Evaluations of procedural justice

From a procedural perspective, on average a higher degree of household participation, control, and transparency led to higher perceptions of justice (Fig. 5). However, there are exceptions to this pattern, as shown in the following paragraphs.

4.1.3.1. Household participation. Comparing the cases, household participation did not always lead to higher justice evaluations. Participation was a challenge in all cases. First, justice evaluations depended on the details of the household representation. Two projects, GF and LEM, had a formal representation mechanism, with clear communication channels between the representatives and the project consortium. In GF, however, the communication between the representatives and the remaining households was less clear than in LEM. Interviewees questioned the extent to which the team really represented the neighborhood. Therefore, participation in GF was evaluated less favorable than in LEM, confirming the importance of establishing clear participation procedures *within* a community (Forman, 2017).

Second, a technology-focused approach made participation

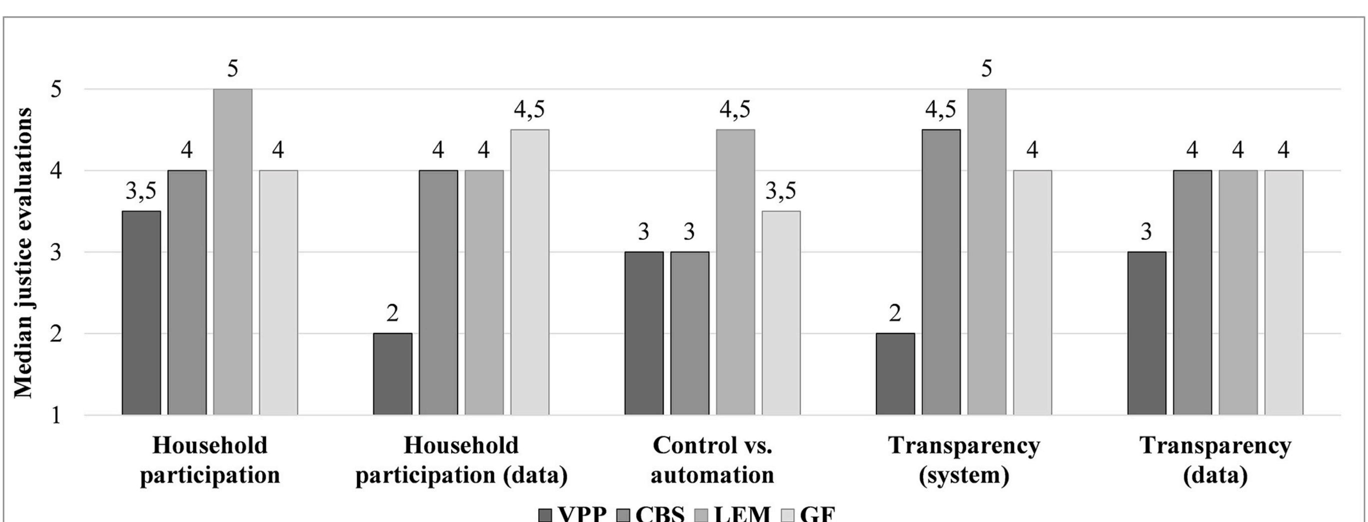

Fig. 5. Evaluations of procedural justice across cases.

challenging. In GF, technical issues with the battery system shifted the user-centric mindset of many consortium members to a technology-oriented mindset. The problems were a side effect of the higher complexity than in other projects: implementing sea salt rather than lithium-ion batteries, a choice for sustainability over technological maturity; and testing multiple smart grid innovations, storage systems and variable network tariffs. This shows that an overreliance on technology can be detrimental to the communication with users and hence their participation (Hansen et al., 2020). In this study, even GF, a project that had all intentions to be very community-oriented and user-centric became absorbed by technological challenges. The electricity system is complex enough as it is and for user-centric design, the application of relatively mature technologies might be advantageous.

Third, comparing VPP and CBS shows that justice evaluations depended on the extent to which decisions with the most visible impact on households were participatory. Both projects had a top-down approach. There was no participatory decision-making in VPP, which was evaluated as somewhat unfair. CBS also had a top-down approach, yet household participation was evaluated as somewhat fair. This might be because households could influence one of the most important decisions regarding the community battery: the exact location and visual design of the battery container. Additionally, the main visible technology – the battery – was not installed in the homes and thus seen as more removed from the private space than in the other projects. This confirms that for participation to be fair, the project decisions with high importance for users and low degree of reversibility should be participatory (Sovacool and Dworkin, 2015).

None of the projects implemented household participation through collaborative ownership of assets, although this is a very important aspect of citizen participation in other areas of the energy transition, e.g. in the implementation of wind and solar parks, and has been shown to foster the acceptance of such energy projects (Cowell et al., 2011). Collective ownership of smart grid assets might be especially relevant for community storage. Accordingly, Kalkbrenner (2019, p. 1361) argues that co-ownership, collaborative business models, and shared resources could be encouraged as tools to engage citizens in local energy systems and "represent a step toward more sustainable production and consumption patterns".

4.1.3.2. Control vs. automation. Our results generally show that higher user control would lead to increased justice evaluations. User control depends on the design of the user interface of the HEMS and ideally, interviewees agreed, meaningful household control would involve that users are able to decide how much they want to control. In the LEM project, for example, which received the highest justice evaluations, the P2P trading is fully automated in the default settings, but households can view what the algorithm has come up with, and have the option to configure trading settings.

At the same time, however, as much automation as possible was considered necessary to guarantee ease-of-use, comparing use to the simple act of switching on lights. Ease-of-use is also important for high accessibility to people with low IT literacy. The VPP and CBS project chose as a consequence for full automation of the batteries. In VPP, this was seen as somewhat unfair, because households did not have insight into the why and how of battery steering. Yet it had an impact on them; it influenced their energy costs, and batteries were noisy and heated up during (dis)charging. In CBS, external control might have been more acceptable than in VPP due to the greater physical distance between households and the community battery (installed at the street corner) compared to VPP batteries (installed in homes).

These findings highlight a fundamental tension for digitalization in energy systems. Smart grids aim to decrease complexities of governing electricity systems under large shares of renewables and are also supposed to give prosumers more control over their electricity use (Michalec et al., 2019). Yet the management of these IT systems relies on considerable expertise to create and operate software, which mediates users' control of the system. This potentially decreases users' control, increases IT dependency, and shifts power towards software operators (Buth et al., 2019). Our findings suggest that transparency is key to design for fair control and reduce this tension. A higher degree of automation is acceptable as long as users have insight into the system steering and can understand e.g. battery behavior. We will focus on system transparency next.

4.1.3.3. Transparency. Similar to our results for household control, transparency is determined largely by the design of the HEMS user interfaces and higher transparency was evaluated as more fair. GF's user interface was evaluated as transparent and relatively easy to use. The app reflected the project's variable tariffs using green/orange/red traffic lights to show network load levels affecting the tariff. The traffic lights gave households the possibility to make an informed decision regarding energy use. However, acting in response did require conscious efforts by users. The app would not show the source of the load, or the household's contribution to the collective load. The latter is critical information, though, since the collective community load determines benefits. For successful collective action, the user interface should show real-time feedback on individual's contribution and include features that allow individuals to coordinate their actions (Bourazeri and Pitt, 2018).

VPP provides an example of insufficient transparency. (Dis)charging was done to optimize trading and not coupled with use and generation patterns of the households. The user interface did not show information regarding external actions by the aggregator, and the battery behavior was thus not comprehensible for households. The lack of transparency interrupted households' trajectory to energy conscious citizens, which had started when they first installed solar panels. Many households saw participation in VPP as a logical next step in their engagement with the electricity system. However, the 'black box' VPP, in addition to the full external control, led to less engagement and monitoring of energy patterns (Gerritse et al., 2019). This highlights again the paradoxical situation that technologies which are in principle intended to increase the accessibility of the electricity system for consumers and enable them to take a more active role in the energy transition interrupted the process of prosumer engagement with the system (Goulden et al., 2014). Especially with electricity, which is invisible and removed from people's consciousness, designers should ensure that users can understand and meaningfully act in response to the information they get.

4.2. Dynamic interrelations between dimensions of justice

After discussing the evaluation criteria one-by-one in the previous section, we now address design complexities that arise from interrelations between the three dimensions of justice. Indeed, our results show that the separation in three dimensions is analytically useful, but that in practice they are closely interrelated (Bulkeley et al., 2014). These interrelations need to be analyzed to fully understand injustices and address them through design. First, and with respect to distributive justice, we find that it was related to perceptions of fair and transparent processes. For example, allocating profits to individuals or to the collective was perceived as fair depending on whether there was an individual or collective process of achieving those profits. Additionally, fairness of data governance depended on transparency and participatory decision-making. These findings confirm that perceptions of procedural justice are instrumentally linked to perceptions of distributive justice (Folger, 1987; Mundaca et al., 2018). Fair procedures can be enabled, among others, by material participation through community co-ownership (Bidwell, 2016; Cowell et al., 2011). Our findings add a form of material participation through household control of smart grid technologies. In fact, the smart grid itself is a process to achieve outcomes – for example energy savings – and the extent of household control over this process influenced perceptions of distributive justice.

Secondly, our findings confirm the importance of recognition as a separate justice dimension (Schlosberg, 2007). Especially accessibility and inclusiveness of smart grid systems influenced general justice perceptions across cases. Recognition thus underpins and enables procedural and distributive justice. A lack of recognition of specific groups and their characteristics will not result in a truly just process that is participatory for this group (Schlosberg, 2007). Distributive outcomes are also likely to be affected, with misrecognition of those people's needs resulting in unequitable distribution of benefits and harms (Bulkeley et al., 2014). The attention to justice as recognition thus gives legitimate reasons to address distributive injustices in smart grid design and policies.

Thirdly, our findings reveal a conflict between procedural and recognition justice that pertains to the design of user interfaces and algorithms. Procedurally, high user control and transparency is considered fair and necessary. Households need to be able to influence how their profits and costs are generated, understand who gains and pays what, and know how their personal data is used. Yet a high degree of transparency and control might increase the complexity of the user interface design, potentially compromising the ease-of-use and therefore inclusive accessibility. This tension highlights the necessity for simple solutions that are still transparent for users (Paetz et al., 2011). GF's traffic light system is an example of such a solution.

Incorporating all three dimensions of justice in this study was useful to understand in depth why design choices regarding distributive aspects are seen as (un)fair. Therefore, highlighting interrelations between the dimensions is needed to provide recommendations how design can contribute to justice. These insights would not have been possible with a narrow focus on distributive issues that is taken in the few existing studies on energy justice for smart grids (e.g. Neuteleers et al., 2017).

4.3. Design for replication and expansion

The design considerations above have focused on the scope of a pilot project. Yet, pilot projects are implemented to serve as experience for future applications in different contexts (replication) and at a larger scale (expansion) and this should be taken into account in the design of pilots. However, our findings indicate that this is typically not the case. This is problematic and risks embedding injustices in future smart electricity systems, since a range of design choices were only seen as acceptable in the context of the pilot project, but not fair in context of a regular retail market offering. Examples are the equal distribution of profits to participating households in VPP, and the use of personal household data and full automation of batteries in VPP and CBS.

These design choices were justified in the project context based on the projects' aim and budget and on their framing as research and development. Thereby, the involvement of the DSOs and universities, and the public funding of the projects instilled trust in households that the project would be designed and operated in an acceptable manner. It is unlikely, however, that future market-based smart grid services will be offered in similar private-public collaborations; the electricity sector actors most likely to offer such services are energy suppliers and aggregators.

Considering the system's future applications from the design onwards might avoid embedding structural injustices. Two design choices seem especially important for replication and expansion. Firstly, a greater emphasis on a structured approach to knowledge sharing than we found in our case studies. Secondly, accessibility can be enhanced by not requiring all participants to own PV and batteries, implementing community storage, or a collective generation facility. Whereas our framework was used in this study to evaluate the structural design of smart grids and compare in a cross-sectional manner four different projects, it might also be used in a longitudinal evaluation of justice over the course of projects.

5. Conclusion and policy implications

This paper analyzed how design choices in four Dutch smart grid pilot projects influenced evaluations of energy justice. It contributes to energy justice literature by providing insight how to design for distributive, recognition, and procedural justice. Based on the findings, we put forth the following recommendations to organizations that want to implement smart grids, be that distribution system operators, hardware and software developers, aggregators, or energy cooperatives. From a distributive perspective, designing for justice involves not only the fair distribution of financial profits and costs, but also the extent of public funding, the active sharing of projects' learnings with the wider public, and fairness in the collection and use of household data. Design for justice as recognition entails ensuring the accessibility of benefits from smart grids to all energy users. This covers in particular accessibility for low-income groups, tenants, households without the physical space for PV systems and batteries, and users with low IT literacy. To enable procedural justice, designers should open decision-making processes to user participation, allow material participation through user control of HEMS, and focus on system transparency. Participatory decision-making should thereby apply most importantly to decisions on cost/profit distribution, data governance, the design of the user interface, and the physical design and placement of storage systems. Designing smart grids for justice should also include conscious design for a fair expansion to larger-scale market services, in order to avoid embedding injustices structurally in the technologies. To do so, designers should especially focus on knowledge sharing and system accessibility.

The comparison of four cases limits generalizability, but our approach was consistent with the aim to analyze *why* certain design choices are considered more fair than others (Yin, 2014). It provided detailed and context-dependent insights into interrelations between justice dimension, and how these can be addressed through design. Future research should focus more on justice as recognition, which is undertheorized (Bulkeley et al., 2014). Yet misrecognition of vulnerable groups can be the starting point for procedural and distributive injustices.

Future research might also explore the feasibility and effects of governance as commons and collective ownership in smart grid systems. High justice evaluations of the collective effort to generate and use electricity locally and therefore gain collective benefits suggest that this can be useful to enable distributive justice. Additionally, collective ownership is an important aspect of citizen participation in the energy transition. This would be a fruitful avenue for (energy) justice research, not the least because there is a knowledge gap regarding commons governance in socio-technical systems (Acosta et al., 2018; Melville et al., 2017). The question whether notions of commons governance and collective ownership might be extended from the boundaries of local smart grids to national electricity networks more broadly might also warrant academic discussions.

Although we did not detail the role of trust, our findings are consistent with previous research showing that trust between households and consortium members positively influenced justice evaluations (Dwyer and Bidwell, 2019). Thus, future research could emphasize how to build trust in a smart grid context and how user interfaces mediate trust between users and software developers.

Our study has implications for policymakers. As smart grid pilots rely on public funding (Gangale et al., 2017), funding organizations – in the Netherlands for example the Netherlands Enterprise Agency (RVO) – can use the evaluation framework developed in this paper to incorporate energy justice in funding criteria. We particularly emphasize that funds should be directed to projects that are complementary and replicable. A barrier for knowledge sharing is likely to remain, because of tensions between design for openness and development of proprietary business models. However, public money should be spent for public benefits, and funds primarily given to projects that develop open platforms and business models. Additionally, funding bodies should ensure that benefits from smart grid technologies are accessible to diverse societal groups. The focus on home owners in most projects risks structural misrecognition of the needs of other groups in society. More targeted experimentation with vulnerable groups which face higher complexities for smart grid deployment, particularly social housing and low-income communities, is needed to understand those users' preferences and energy practices.

Moreover, our findings have implications for electricity sector regulation, especially for storage. Storage is one of the most important local flexibility-providing technologies, but faces institutional barriers. Among others, the current net metering scheme implies that storage has no financial viability for residential prosumers. A replacement rule for net metering, which will be phased out from 2023 onwards, decreases the reward for feed-in of renewable generation, thus making storage financially more attractive (Directoraat-generaal Klimaat en Energie, 2019b). Policy makers should strike a balance between incentivizing self-consumption while not deterring renewable generation and endangering renewables targets. Next, policymakers should facilitate the collective ownership of community storage as this is already an important mechanism to enable procedural and distributive justice for e.g. wind and solar parks. In addition, storage falls within the definition of both producer and consumer of energy, and as a consequence of this and strict ownership unbundling of commercial activities and network operation, DSOs are prohibited to own and operate storage (Mir Mohammadi Kooshknow and Davis, 2018). Policymakers should adjust regulation so that DSOs can benefit from storage owned by market parties for grid-stabilizing services.

Finally, this paper is a response to the increasing importance of justice in energy transitions. The value of justice has gained remarkable salience in the political debate on sustainability transitions (European Commission, 2019; UNFCCC, 2018).Academic literature on energy justice has been growing as well, but has little impact on policymakers and technology developers (Galvin, 2020; Jenkins, 2018). Our study contributes here by giving actionable recommendations how technology developers and policymakers can consciously design smart grid systems that are not only smart, but also equitable and inclusive.

CRediT authorship contribution statement

Christine Milchram: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Rolf Künneke:** Validation, Writing - review & editing, Funding acquisition. **Neelke Doorn:** Validation, Writing - review & editing. **Geerten van de Kaa:** Validation, Writing - review & editing, Funding acquisition. **Rafaela Hillerbrand:** Writing - review & editing, Funding acquisition.

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.

Acknowledgements

This work was supported by the Netherlands Organization for Scientific Research (NWO) under the Responsible Innovation Program [Grant No. 313-99-305]. The authors thank all interviewees for sharing their insights on the pilot projects.

APPENDIX

Appendix A. Interview guidelines

Interview Guidelines	
PART 1: PROJECT AND INTERVIEWEE'S ROLE	
1. Could you explain what your role in the project is?	
2. When did you become involved in the project? At what stage of the project was that?	
3. In your opinion, what was the main reason for starting the project?	
4. Do you think the project was successful? Why / why not?	
PART 2: EVALUATIONS OF JUSTICE	
Allocation mechanisms	
5. How fair / unfair do you think are profits divided among the households? Why?Probing categories: Monetary benefits, energy savings; high and low income households, people who own and people who rent their homes, prosumers and consumers	1 – 5 = very unfair – very fair (don't know)
6. How fair / unfair do you think are costs divided among the households? Why?	1 – 5 = very unfair – very fair (don't know)
7. What do you think about the spending of public money on this smart grid experiment? Why?Probing categories: by the government, by the DSOs	1 – 5 = very unfair – very fair (don't know)
8. When you think about the knowledge that is gained from the project: What do you think about the availability of knowledge to the wider public? Why?	1 – 5 = very unfair – very fair (don't know)
IT Systems	
9. How much IT knowledge must users have? How fair or unfair is this in your opinion? Why?	1 – 5 = very unfair – very fair (don't know)
10. Think about how the extent to which households can control the system in comparison to how much is automated: How fair or unfair is this? Why?Probing question: What options do users have to overrule automated system functions?	1 – 5 = very unfair – very fair (don't know)
11. When you think about the way households get informed of their electricity use: How transparent is it for users to understand the effect of their behavior on electricity use? Why?Probing question: How do users receive this information?	1 – 5 = very opaque – very transparent (don't know)
Management of household data	
12. How fair or unfair do you find the way how household data is collected and used by the project partners? Why?Probing questions: What data is collected? How and by whom are data collected, accessed, used?	1 – 5 = very unfair – very fair (don't know)
13. Did users have an influence on decisions how to collect, access, use, their data? How fair or unfair do you think is that? Why?	1 – 5 = very unfair – very fair (don't know)
14. How transparent is it for households who has access to their data and how? Why?	1 – 5 = very opaque – very transparent (don't know)

(*continued on next page*)

(*continued*)

Interview Guidelines	
Collaboration in the project	
15. When you think back how you selected the community: Why did you decide for [community]? How fair or unfair is that? Why?	1 – 5 = very unfair – very fair (don't know)
16. How fair or unfair do you think were the criteria for selecting households? Why?Probing questions: Selection criteria for households? How were households approached, selected, and how did they decide about participating?	1 – 5 = very unfair – very fair (don't know)
17. How are users included in decision-making processes? How fair or unfair is this in your opinion? Why?	1 – 5 = very unfair – very fair (don't know)
Scaling-up and replication	
18. To what extent would the technology be accessible for different user groups? How fair or unfair do you find that? Why?Probing categories: people who own their home and live in it, people who live in a rented home, people who live in social housing, low-income citizens, people who do not produce their own electricity	1 – 5 = very unfair – very fair (don't know)

Appendix B. Overview of design choices relevant for energy justice across cases

Table A.1
Design choices relevant for energy justice across cases

Justice Evaluation Criteria	VPP	CBS	LEM	GF
Distributive				
Distribution of profits	Individual: Profits from trading mode distributed equally to households Allocation of batteries: 1 battery/household	Individual: 50% discount on rent of PV for one year for all households Allocation of battery capacity: same capacity for all households	Individual: Profits from P2P trading based on household's choices Allocation of batteries: 3 batteries/16 households, diversity-based allocation	Collective: Electricity cost savings distributed to collective for collective spending Allocation of batteries: 20 batteries/47 households, space-based allocation
Distribution of costs	'Not more than usual' principle for households Compensation of battery losses	'Not more than usual' principle for households	No household cost for smart grid system No compensation of battery losses	'Not more than usual' principle for households Compensation of battery losses
Public funding	Yes: European Union	Yes: national subsidy	Yes: partly DSO-funded	Yes: national subsidy
Knowledge sharing	High	Moderate	Moderate	Moderate
Data governance	Smart meter data linked to households shared within project consortium One smart meter per household	Smart meter data linked to household shared within project consortium	Smart meter data linked to households shared within project consortium Separate meters for generation, appliances, heat pump, storage	Smart meter data anonymized before sharing within project consortium 'Privacy by Design' designation
Recognition				
Selection of community	Selection based on existing infrastructure/technology	Selection based on existing infrastructure/technology	Self-selection by community	Selection based on existing infrastructure/technology
Selection of participants	Self-selection	Self-selection	Self-selection	Self-selection
Technology accessibility	Low Participation requirements: Location, PV system, Home battery	Moderate Participation requirements: Location, PV system	High Participation requirements: Location	Moderate to high Participation requirements: Location
IT literacy required	Low	Low	Moderate	Moderate
Procedural				
Household participation (general)	Low: no formal procedures information evenings for households	Low: no formal procedures information evenings for households	Medium: participation through one dedicated user representative	High: participation through dedicated user representation committee
Household participation (data)	Low: consent	Low: consent	Medium: influence on data collection mechanism	Medium: influence on data collection mechanism
Control vs. automation	No household control Full automation	No household control Full automation	High household control Full automation possible	Moderate household control Full automation possible
Transparency (general system)	User interface: generation, use, storage	User interface: generation, use, storage	User interface: generation, use, storage, settings for P2P trading	User interface: generation, use, storage, pricing status
Transparency (data)	Data collection and use specified in user contract	Data collection and use specified in user contract	Data collection and use specified in user contract	Data collection and use specified in user contract

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