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## Design choices for consumer governance

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# Participation of active consumers in the electricity system: Design choices for consumer governance

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ABSTRACT

Household electricity use has an increasing impact on the overall energy system. Numerous proposals have been made to support households to consume electricity in a system-friendlier manner. By breaking these proposals down into functions and how they are performed, this paper identifies four distinctive governance designs: energy communities, variable electricity tariffs, local energy markets and virtual power plants. None covers all the functions required and each addresses different trade-offs that households face. Energy communities focus on investing in energy assets, while the others target the operation of households' assets, including demand response. Virtual power plants attract profit-oriented consumers, while the others primarily target normative consumers.

## 1. Introduction

Households possess an increasing potential to respond flexibly to the availability of renewable energy and grid capacity [1]. Therefore, they could play a significant role in the integration of renewable energy and decarbonization of the electricity sector, but this is hindered by the limited time available to manage their response [2]. In this paper, we address how the governance of households – the interface between households and the electricity system – can be designed to maximize the benefits of their flexibility and self-generation of electricity, while still respecting their needs and constraints.

We provide an extensive review of the literature on the governance designs for household interactions with the electricity system and apply a formal design framework [3] to compare them.

Households own a growing number of energy assets capable of supplying or consuming electricity in a flexible manner. Self-generation of electricity, e.g., with rooftop solar panels, and demand-side flexibility, e.g., when charging electric vehicles or operating heat pumps and home batteries, can help to integrate renewable energy into the energy system [1]. Active consumers can adjust the use of these assets to the system-wide availability of renewable electricity and thereby reduce the mismatch between the supply of wind and solar energy and electricity demand [4]. A second potential benefit of consumer flexibility is that it can be used to reduce congestion in electricity distribution networks [5].

Intermediaries act as brokers between consumers and the electricity system to organize electricity supply [6]. Economies of scale combined with legal, commercial, financial and technical expertise allow them to organize the electricity supply more efficiently than individual consumers can [7]. From the perspective of Transaction Cost Economics (TCE), such brokers facilitate participation by reducing the transaction costs for consumers [6,8]. Such arrangements are considered attractive if their benefits offset the induced transaction costs of consumers [9].

The intermediary faces two challenges when designing attractive packages. First, the agreements need to reflect heterogeneous consumer requirements and be formalized in a contract [6,10]. Second, the contractual arrangements need to align with the requirements of the electricity sector, its market design, and regulations. The latter particularly concerns incentives in the form of price signals from the electricity grid, the market, or administrative price elements [11]. If these challenges are successfully addressed, such packages represent a new governance design that enable an electricity system-friendly operation of the energy and flexibility assets owned by consumers.

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*Abbreviations:* CPP, Critical Peak Pricing; LMP, Locational Marginal Prices; PTR, Peak Time Rebates; RTP, Real-Time Pricing; TCE, Transaction Cost Economics; ToU, Time of Use Pricing; VPP, Virtual Power Plants.

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There are individual strings of literature that propose new governance designs (such as [12–14] on variable tariffs [7,15,16]; on virtual power plants [17–19]; on local energy markets and [20–22] on energy communities), and discuss their performance (such as [4,23]) and the compatibility of contractual and regulatory arrangements (such as [24]). However, the fragmented research and partly overlapping proposals make it difficult to compare the different designs to each other and develop them further.

We therefore reviewed the literature on governance designs, their corresponding regulatory arrangements, and their performance in a coherent, structured manner following the Function-based Design Analysis by Knops and de Vries [3]. This review framework is introduced in Section 2 and applied to develop an inventory of designs in Section 3 before identifying archetypical designs and discussing their performance in Section 4.

## 2. Review framework

We reviewed the literature following the Function-based Design Analysis by Knops and de Vries [3] and grouped and categorized the numerous proposed designs by the degree to which the benefits offset the transaction costs. The review framework and its design perspective were motivated by the fact that governance is an artifact in a socio-technical system, which consists of different actors, roles, and rules and, therefore, can be shaped in various ways to meet their requirements [3,25,26].

The review framework involved three steps, which are illustrated in Fig. 1 and explained in the following. First, we extracted the required functions and corresponding design choices for the participation of households in the energy system from the literature. Second, based on this inventory, we identified archetypical combinations of the design choices in the literature. Third, we categorized them by their performance.

**Step 1: Development of an inventory of functions and design choices for consumer governance design**

Each consumer governance design includes price signals set by the regulator as incentives for system-friendly operation of energy assets, support by the intermediary to organize the response of the households towards price signals, as well as elements to enable the responses. These three kinds of functions can be recognized as recurrent patterns in the proposed governance designs in the literature.

To reveal the patterns, we broke down the proposals into their design choices and structured them in an inventory (see section 3). This approach was taken from Dijkema [27], who recommends assessing a complex design based on its smallest elements that serve an objective, i.e., its functions, and how they are performed, i.e., the design choices. Knops and de Vries [3] formalized this recommendation for the electricity system in their so-called Function-based Design Analysis. So far, this has been applied to other parts of the electricity system, such as the balancing market [28,29] and distribution system [29]. It states that the governance design is characterized by the performance of its organizational functions, which steer the technical functions of electricity supply (e.g., generate, distribute, consume) towards the objectives of the electricity system (e.g., cost-efficient electricity supply) [3].

In the context of the governance design for active consumers, we identified eight functions and two or three design choices for each function, which are illustrated as differently colored hexagons in Fig. 1.

**Step 2: Identification of consumer governance archetypes**

Some combinations of design choices are mentioned more frequently in the literature than others. In the second step, we describe these as governance design archetypes based on the inventory of step 1 and analyze them further. At the level of individual archetypes, we identified dependencies for the selection of design choices and so far unspecified design choices, which are indicated by an X in Fig. 1. Comparing the governance designs for passive and active consumers, as well as comparing the new designs for active consumers among each other revealed similar and distinct design choices.

Fig. 1 shows four archetypes for active consumers, which are elaborated in Section 4. We used a flat tariff offered by a retailer as a reference design for passive consumers. Retailers organize grid access with grid operators and purchase electricity from the wholesale market based on a contract. Electricity flow is unidirectional, and consumers are charged a flat retail price by the intermediary, as illustrated in Fig. 2.

Interactions are different for the four new archetypes for active consumers: The intermediary receives price signals and translates them for the consumers. Electricity flows between consumers and other market participants as a response to this signal. If needed, additional investments in energy assets are made. The intermediary receives consumption data and payments, which are allocated to the involved actors.

Apart from traditional retailers (e.g., Refs. [16,30]), new intermediary actors facilitate the participation of households, such as aggregators (e.g., Refs. [7,16]), energy service providers (e.g., Refs. [6,30]), or community energy operators (e.g., Refs. [2,22]).

**Step 3: Indicative performance evaluation of consumer governance archetypes**

In the third step (see Section 4), we categorized the performance of the governance archetypes by the degree to which their benefits offset the transaction costs. The overall attractiveness, as well as the trade-offs

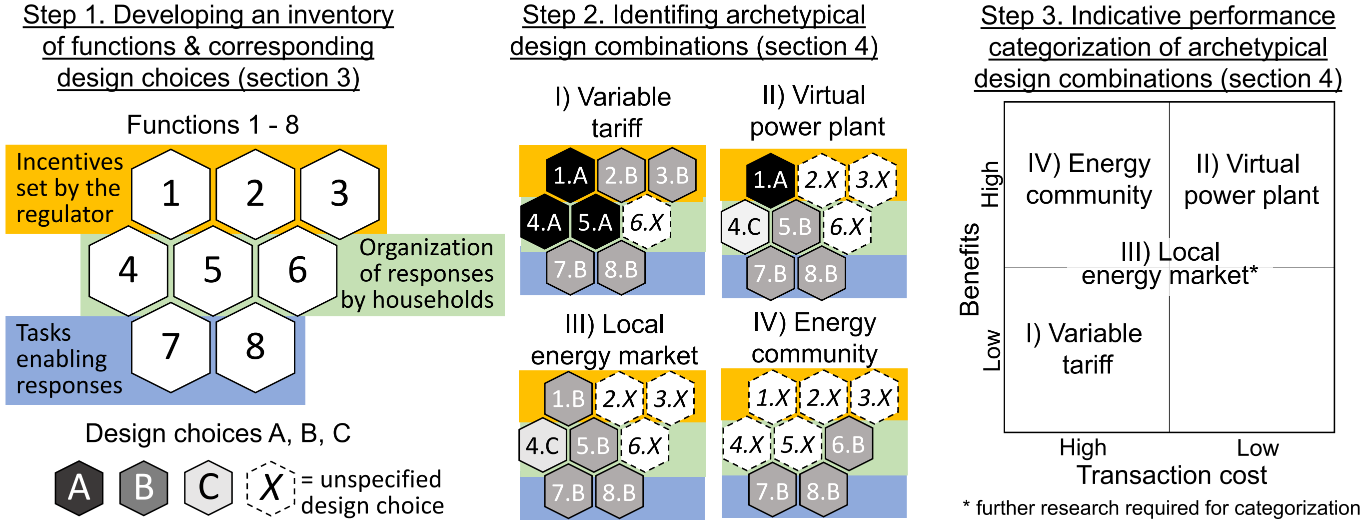

**Fig. 1.** Review framework for grouping governance designs for active consumers and categorizing their performance.

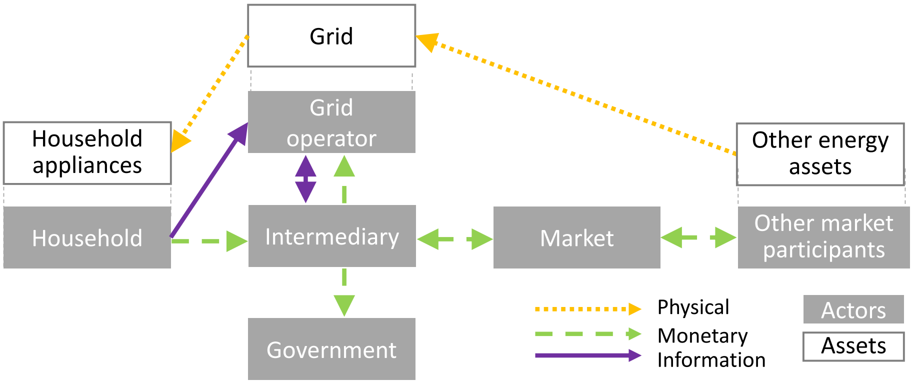

**Fig. 2.** Actors, roles, and interactions in traditional electricity exchange.

between the transaction costs and benefits, allow us to draw conclusions for the further development of the governance designs. If a design is considered promising, the existing archetypes of step 2 can be gradually adapted in regard to their design dependencies and unspecified design choices. If not, new design combinations can be created based on the inventory of step 1.

We applied the concepts of TCE to structure and compare different cost and benefit aspects that are presented in the literature. On the one hand, we used three determinants suggested by Dahlman [31] for the analysis of transaction costs: frequency of the interactions, uncertainty, and asset specificity. We consider these relevant for consumer governance, as they can be detected in the basic governance description in Section 2.2: The intermediary aims to minimize transaction costs by reducing interactions with other actors, bearing price and forecasting uncertainty, and providing human (e.g., knowledge, expertise) and physical assets (e.g., smart metering) required for the interactions [6].

On the other hand, the benefits depend on the degree to which the requirements of consumers and the electricity system are met by the governance design. Since each consumer may exhibit multiple requirements, the governance design needs to adapt to their specific requirements to varying degrees.

Steg et al. [10] identified four motivations of consumers that explain their requirements: Egoistic consumers aim to minimize costs; altruistic consumers focus on ways to support others; and biospheric consumers care about the consequences for the environment. The latter two are grouped together under the term normative motivation. Hedonistic consumers desire pleasure and low effort, which is valid for all consumers to a certain degree and reflected in the transaction costs.

Most consumers are prepared to become active consumers in order to minimize their supply cost (egoistic motivation) and support the decarbonization of the electricity system and renewable integration (normative motivation) [32–34]. For some consumers, this is also linked to their mistrust in incumbent players and results in additional objectives of trust-building [35], such as creating transparency for pricing, the origin of electricity [36,37], and the usage of smart meter data [38–40], as well as empowering local and sustainable initiatives [41–43]. Consumer requirements are summarized in Table 1.

On the side of the electricity system, generation, storage, distribution, consumption, and measurement of electricity are the main technical functions. They are operated to serve the needs of consumers, but these needs do not necessarily comprise all the requirements for the system. In general, electricity policy needs to balance the following requirements [46]:

- security of supply,
- cost-efficiency and,
- decarbonization of the electricity supply.

**Table 1**
Requirements of active consumers.

| Motivation | Consumer requirement | Source |
|---|---|---|
| Egoistic | Minimize their electricity cost | [1,4,42] |
| Hedonistic | Minimize their transaction cost | [6,44,45] |
| Normative | Decarbonize their electricity supply, | [32–34] |
| | safeguard data privacy, | [38–40] |
| | create price transparency and enable control, | [36,37] |
| | empower local and sustainable initiatives | [41–43] |

To which degree these are met by the governance design and how their performance is linked to the design choices is discussed in Section 4. In this context, price signals play a major role, since they are the key mechanism for achieving all three requirements. The low marginal cost of renewable electricity results in low wholesale market prices. Therefore, they are consumed first before other types of electricity generation. Price peaks during the absence of renewables incite investments in flexibility assets to maintain the security of supply [47]. Such a steering effect is not only associated with the market price signals, but also with other price signals from the electricity grid and with administrative elements of the retail price.

The design of these three price signals is influenced by the EU's decision for a zonal energy-only market [46], which gives the scope for assessing consumer governance design. This means that, first, only electricity that has actually been produced is remunerated and not its mere readiness as is the case in capacity markets [48]. Second, grid congestions are managed after the gate closure of the wholesale market and are not reflected in the market price [49].

## 3. Design choices for a governance design for active electricity consumers

Design choices represent different ways of performing the three kinds of functions. The three functions concerning the first kind, price signals, were introduced in Section 2.3. To incite system-friendly operation of energy assets, the regulator designs market price signals that match electricity and flexibility, grid signals for congestion management, and administrative price elements.

As described in Section 2.2, the intermediary supports households in their response to price signals (second kind) by performing three functions: Translating the price signals for the households, operating the energy assets, and investing in new energy assets, if needed. These activities are based on collected and analyzed data, and billed afterward (third kind). The design choices for each function are listed in Table 2 and described in the following sections.

### 3.1. Matching electricity and flexibility

Price signals from the wholesale market steer the matching of demand and supply. Whether the wholesale market is accessible for small

**Table 2**
Functions (1–8) and their design choices (A, B, or C) for the consumer governance design.

| Incentives set by the regulator | Organization of the response by households to the incentives | Tasks enabling the response of households |
|---|---|---|
| ***F1 Matching electricity and flexibility*** | ***F4 Pricing for consumers*** | ***F7 Data collection*** |
| A. Aggregation | A. Variable tariff | A. Yearly metering |
| B. Local energy market | B. Flat tariff | B. High resolution and frequency of metering |
| | C. Business model | |
| ***F2 Congestion management*** | ***F5 Operation of energy assets*** | ***F8 Billing*** |
| A. Technical intervention | A. Indirect coordination | A. Yearly billing |
| B. Congestion pricing | B. Direct coordination | B. Continuous billing |
| C. Flexibility market | | |
| ***F3 Allocation of administrative price elements*** | ***F6 Investment in energy assets*** | |
| A. Volume-based | A. Individual investment | |
| B. Capacity-based | B. Collective investment | |
| C. Fixed | C. Investment-*as*-a-service | |

assets owned by households depends on the market access regulation and prequalification requirements. Small assets can be aggregated to meet requirements. Alternatively, intermediary markets with lower entrance thresholds can be created [16]. In the literature, such markets are frequently restricted to a small geographic area and referred to as local energy markets. Their restricted market access serves at the same time as a guarantee of origin for the participating consumers [50]. There are two main design choices here: aggregation and local energy market.

Regarding aggregation, Glachant [30] describes aggregators as reverse retailers who provide flexibility and electricity from consumers to the wholesale or other markets. Heterogeneous assets in a well-combined portfolio complement each other and create electricity products that meet the needs of the market [7]. A central control system connects them to one entity [51].

In contrast to aggregation, which aims to comply with the conditions of established markets, the local energy market creates a two-sided market platform with its own conditions and trading processes [30]. Consumers represent both sides of the market and interact in close proximity, connected by a public or private grid [50]. The trading process includes both local interactions and interactions with the wholesale market and the grid [50].

Without standardization by a regulator, different market architectures of local energy markets may emerge with regard to two aspects. On the one hand, the dispatch of demand and supply can be organized in a market with auctions and bids, or hierarchically by an optimization process considering the objectives and constraints of the participants [17–19]. Common market-based organizations in the literature are peer-to-peer and transactive energy markets; common hierarchical organizations are community or collective self-consumption [18]. On the other hand, the geographic dimension and dispatch levels may differ [2,17,18]. Larger markets with auctions are more liquid and transparent. At the same time, smaller hierarchical systems have lower entrance barriers and thus can activate and involve larger numbers of participants [17].

### 3.2. Congestion management

If more grid capacity is used than is installed, price signals can reallocate the utilization of the capacity. The literature proposes two design choices with price signals for congestion management. On the one hand, congestion can be priced into the electricity price or into a variable network tariff. A special form is peak pricing, which deviates from the flat rate tariff only during periods of congestion. On the other hand, a reallocation can be traded in flexibility markets [51–54]. At present, the grid utilization of small assets is not adapted by price signals, but by direct technical interventions of the grid operator. Consequently, there are three design choices when it comes to congestion management: technical interventions, congestion pricing, and a flexibility market.

Technical interventions are scheduled based on the announced consumption and supply plan, and communicated in advance to electricity assets. In return, the assets receive cost reimbursement [55]. For small assets without an announced plan, the grid operator relies on stochastics for the interventions, making communication in advance and cost reimbursement more difficult. For flexible appliances, rules for more extensive technical interventions may be formalized in the grid connection agreement or an additional contract for flexibility provision. Different design specifications of the so-called conditional contract exist regarding its contracted product and constraints of the interruption by the DSO. For instance, such a contract can determine that the DSO can cap the charging capacity of electric vehicles above a certain threshold for grid-friendly charging [56,57].

One congestion pricing design choice is the locational marginal price (LMP) that considers the grid capacity in the dispatch process of the electricity market. In case of capacity limitations, LMP results in different prices for every node of the electricity grid at every time step [56]. If the wholesale market is determined as one pricing zone, variable network tariffs create similar effects to LMP.

Modeling studies demonstrate the efficiency of congestion pricing at distributional level for small assets [58–61], but uncertainties on both sides remain. For the grid operator, translating capacity limitations into variable network tariffs carries the risk of not recovering grid costs. For consumers, geographical differences in pricing tend to be considered unfair, create price uncertainties, and additional monitoring efforts. Both aspects need to be addressed by the tariff design [56,62], which is discussed in Section 3.4.

The third design choice for congestion management, the flexibility market, follows a different paradigm. Instead of pricing grid usage rights, consumers own and trade them on a flexibility market. The grid operator announces a flexibility demand concerning the amount of power required, the location, and the level of reliability [63]. Flexibility can be traded as short-term products (e.g., adapted grid usage for 15 min) or long-term contracts (e.g., right to adapt the load for one year) [56]. One grid operator needs to coordinate the flexibility usage with other grid operators on the same voltage level and higher ones. Calculating the optimal auction outcome is easier for smaller geographical market areas, but a higher degree of coordination is required afterward [63]. Professional support is required at consumer level to forecast the flexibility and for bidding.

### 3.3. Allocation of administrative price elements

The design of taxes, levies, and other elements of the retail price impact the market-based price signals and thereby the incentives for system-friendly operation [11]. The three design choices are volume-based, capacity-based and fixed allocation.

Volume-based price elements incite consumption reduction but diminish the price signals sent by the grid and market. Capacity-based price elements allow price signals to evolve their incentives for system-friendly behavior if exemptions exist for capacity overruns during these times. Technical installations, such as a fuse or a smart meter, need to monitor and penalize capacity overruns. Fixed-price elements have a similar effect as capacity-based ones without technical monitoring. To set the fixed price, an economically sustainable and non-discriminating calculation logic needs to be determined [64].

### 3.4. Pricing for consumers

Independently of the origin of the price signal, they are transformed into tariffs or other business models for the consumer [30,52]. Apart from the traditional flat tariff, different forms of variable tariffs exist, also called dynamic pricing in the literature. Most design choices require smart metering that labels the consumption per price level with a time stamp.

Various variable tariffs that differ in the intensity of price signals are proposed in the literature (presented in order of decreasing intensity): Real-Time Pricing (RTP), Time of Use Pricing (ToU), Critical Peak Pricing (CPP), and Peak Time Rebates (PTR) [14,65–67]. Pre-determined price levels, a long duration, and small price differentials decrease the incentives for system-friendly behavior and the price risks for consumers [66]. For instance, while RTP sends price signals in the same resolution as on the wholesale market, ToU announces them in advance for a specific day, week, or season. The simplest ToU form is the peak and off-peak tariff, which can be metered by an analog double-rate meter in contrast to the other tariffs. The CPP and PTR only deviate from the flat tariff in rare moments of extreme wholesale prices or grid utilization [65].

Compared to variable tariffs, the flat tariff with one price level involves no price risks for consumers but offers no incentive for system-friendly consumption behavior.

Compared to volume-based tariffs, more complex pricing schemes with bonuses and fees exist and are labeled as business models. For instance, if the intermediary organizes the response to the price signals on behalf of consumers (see direct coordination in Section 3.5), it processes price signals of a high resolution (such as real-time pricing) and presents them in an aggregated form as service fees and bonus to the consumers. In the case of aggregated trading portfolios, it is almost impossible to trace the contribution of a single entity to the overall revenue, so a lump-sum bonus is paid. Ex-ante determined fees or bonuses decrease the risks for consumers [52].

### 3.5. Operation of energy assets

When consumers receive price signals, they are responsible for responding to them by adjusting their consumption or generation. They can be supported through optimized load control by the intermediary. Depending on the coordination role of the intermediary, the design choice is called indirect or direct coordination.

In the case of indirect coordination, the consumers themselves control any adjustment of consumption after receiving the price signals. This increases price transparency and awareness but also the level of effort and the price risk. Indirect coordination in combination with variable prices is also called price-based demand response in the literature [23].

In the case of direct coordination, the intermediary has direct control over the assets according to their operation parameters and consumer requirements. This case is especially applicable for batteries and large, flexible appliances with regular usage patterns and distributed generation, which intermediaries optimize to increase self-consumption or offer trading services. The requirements can be updated more frequently to avoid comfort losses for appliances with irregular usage patterns (e.g., electric vehicles). The direct coordination in combination with bonuses, fees, and penalties for certain consumer behavior is called incentive-based demand response in the literature [23].

### 3.6. Investment in energy assets

If their current infrastructure does not allow consumers to respond to price signals, additional investments, e.g., in a photovoltaic system, can enable them to become active. These require the financial means and the capacity for technical planning and administrative processes. If this exceeds what an individual consumer is capable of, collective investments and investment-as-a-service are other design choice alternatives to individual investments [23].

In the case of individual investments, individual households cooperate with energy service providers on technical planning, financial matters, and administrative processes. They tend to dimension the installed capacity to their consumption needs since the trading of excess electricity involves additional administrative obligations [68].

In the case of the design choice collective investment, larger installed capacities are realized by the collective investments of several households. Instead of being limited to one house, the most suitable location for the efficient operation of the energy asset is selected. Households with a small budget can participate as well [22,24,69]. Additional contractual arrangements are required to define the ownership rights, access, and compliance rules [70]. Since the financial means and the social complexity increase with the number of participants, it is recommended to install control and conflict resolution mechanisms [43,71].

In the case of investment-as-a-service, intermediaries invest in energy assets instead of households and offer their utilization in return for a fee that covers the costs for operation, maintenance, and repair. This innovative business model, which began in the software industry (software-as-a-service), shifts the financial burden and risk to the intermediary [72].

### 3.7. Data collection

After the functions are performed, the consumers send metering data to the intermediary. We differentiate between data granularity and transfer frequency for the design choices [4,44].

In the case of yearly metering, flat rate tariffs are billed based on yearly consumption data, which can be provided by an analog meter.

Most variable tariffs, cost optimization and trading services require the other design choice, metering data with high resolution and frequency [73]. The data are provided by smart meters, which collect the data according to the tariff design, store them temporarily and distribute them after a short period [5].

### 3.8. Billing

In return for the shared data, the intermediary reports the performance to the consumers. Reporting can involve a more detailed price breakdown, information on the origin of the electricity, data usage, or a peer comparison [52]. For the design choices, we differentiate the frequency of reporting. There are two billing choices, yearly or continuous billing.

In yearly billing, consumers receive a paper-based bill for their energy consumption once a year based on the yearly metering.

The second design choice, continuous billing, increases price transparency and consumer awareness. On average, energy savings of 8% are reported for more frequent billing [74]. At the same time, it is recommended to combine this with other motivational interventions (e.g., goal setting), as increased awareness alone does not necessarily result in behavioral changes [75]. To convey the information, alternatives to the paper-based bill include electronic bills or direct reporting via in-house displays and smartphones [74].

## 4. Archetypes of governance designs for active electricity consumers

Several governance designs have been implemented in practice or proposed in the literature. Following section 3, we broke them down into design choices to understand and categorize their performance. This breakdown highlights characteristic design choices and white spaces, for which the design still needs to be specified. It results in an overview of archetypes of new governance designs, which match the different requirements of consumers and the electricity system.

Fig. 3 summarizes the key design choices for each category of functions. Regarding the first category, the identified governance designs follow two different incentive logics set by the regulator. They are either based on existing market and grid signals, or on new markets for active consumers. Concerning the first incentive logic, the governance design of virtual power plants (VPP) and variable tariffs is based on the wholesale market's price signals. Concerning the second incentive logic, new decentralized markets are formed by the local energy market with smart contracts and energy communities. In contrast to the traditional governance design with flat tariffs, the new tariffs require a higher frequency of data collection and billing.

The four archetypes of governance design are based on a few distinctive design choices in combination with their dependent design choices. For instance, indirect coordination as an operation strategy (F5) applies to variable tariffs (F4), whose enforcement is the responsibility of the consumers. In contrast, direct coordination (F5) is positioned as a business model with fees and bonuses (F4). The fees include the costs for forecasting, trading, and enforcement services. The lump-sum bonuses result from aggregated trading portfolios, in which it is almost impossible to determine the contribution of single entities.

Some unspecified design choices, such as congestion management mechanisms (F2) or investments (F6), result in fragmented governance designs. The literature suggests combinations of archetypes to achieve a complete design. Table 3 presents the characterized and unspecified design choices, synonyms, and specifications of each archetype from the literature.

In the following, the characteristic design choices and their performance are presented for the four archetypes based on the available information in the literature. Fig. 4 indicates their performance in a semi-quantitative manner. Whereas the direct coordination and aggregation of the virtual power plant lead to low transaction costs (and therefore high attractiveness), high transaction costs are associated with the variable tariffs and their indirect coordination.

The current state of research on local energy markets is ambiguous about the level of transaction costs and benefits. Further research is needed on the added value normatively motivated and profit-oriented consumers associate with the trust-building features and whether this is sufficient to offset the transaction cost of direct coordination on a geographically limited market. The emerging investment opportunities of energy communities create additional benefits for consumers, but also impose additional transaction costs depending on how they are combined with other governance designs.

### 4.1. Variable tariff

The design of variable tariffs is characterized by how they convey prices to consumers (F4. A) and how consumers respond to them (F5. A). They are designed for consumers who like to control the operation of

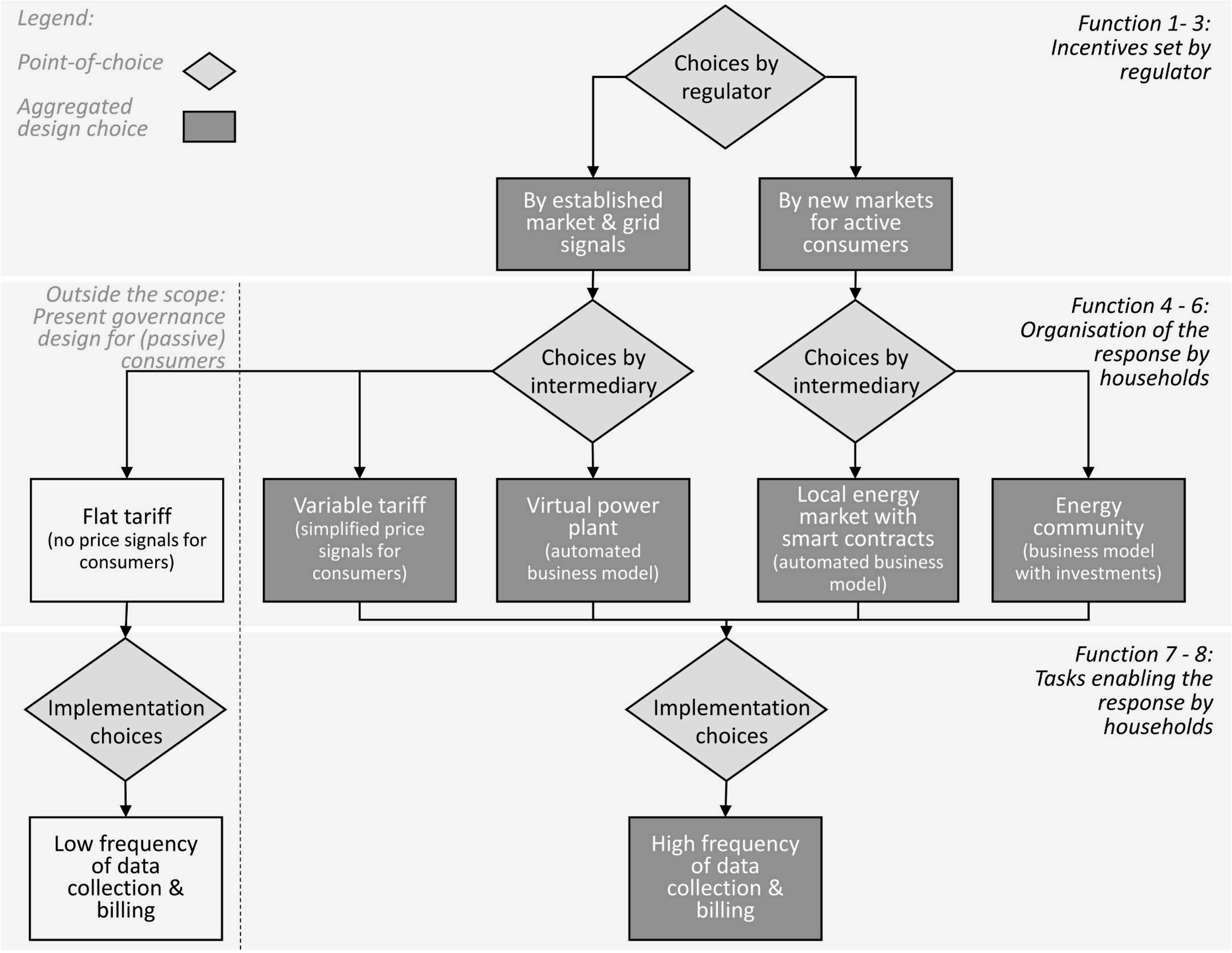

**Fig. 3.** Summary of archetypes of new governance design w.r.t. the design choices from section 3.

**Table 3**
Synonyms, specifications, characteristic and unspecified design choices for the four archetypes of governance design.

| Governance design archetype | Synonyms & key words in the literature | Specification in the literature | Distinctive design choices | Unspecified design choices | Source |
|---|---|---|---|---|---|
| Variable tariff | Dynamic tariff | Real-time pricing, time of use, (critical) peak pricing, peak time rebate | Variable tariff (F4) + indirect coordination (F5) | A specific form of variable tariff (F4), investment in energy assets (F6) | [4,13,14, 65–67,67, 73,76–79] |
| Virtual power plant | Aggregation | – | Aggregation (F1) + direct coordination (F5) | Congestion management (F2), allocation of administrative price element (F3), investment in energy assets (F6) | [7,15,16, 30,51] |
| Local energy market with smart contracts | Decentralized electricity market design, micro energy markets, distributed generation in smart grids, local energy platform | Peer-to-peer trading, microgrid, electricity island, (regional) flexibility market, smart contracts & blockchains | Local energy market (F1) + direct coordination (F5) | Congestion management (F2), allocation of administrative price element (F3), investment in energy assets (F6) | [16,17,19, 30,38,63, 80,81] |
| Energy community | Community-based markets, community-electricity systems, community-based energy initiatives | Collective actions, co-ownership, prosumer communities, self-consumption, prosumer group model, cooperatives | Collective investments (F6) | Matching of electricity and flexibility (F1), congestion management (F2), pricing for consumers (F4), operation of energy assets (F5) | [2,19,20, 24,34,41, 68–71,82] |

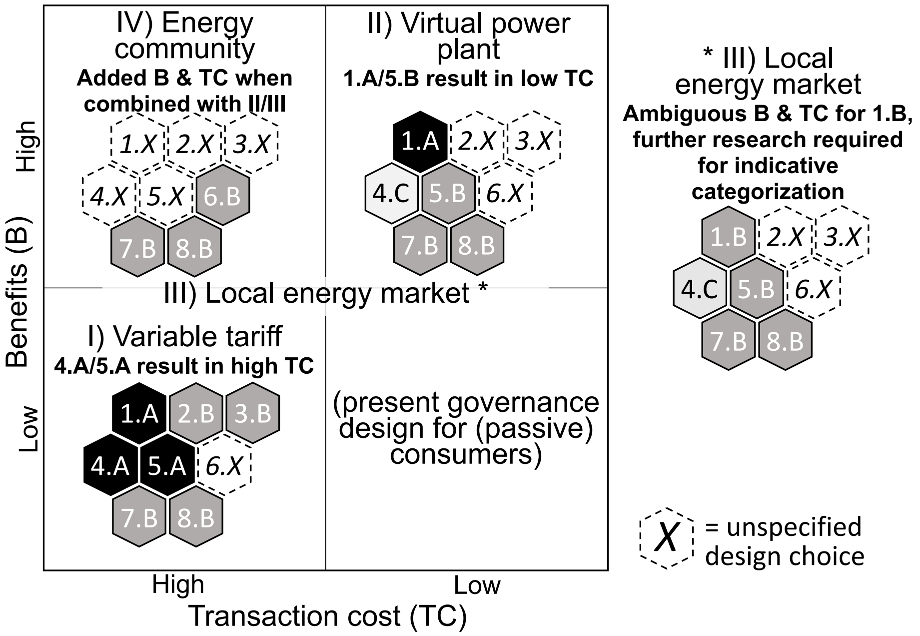

**Fig. 4.** Indicative categorization of the performance of the governance archetypes.

their assets and appreciate transparent price information. The consumers select a variable tariff with an appropriate level of information by balancing these requirements and the monitoring effort. This was discussed in Section 3.4.

Regarding the performance of variable tariffs, field experiments report a reduction in generation capacity and an improvement in economic efficiency with four limitations from a system perspective. First, seasonal differences are reported. Hot months show significantly higher responsiveness than mild and cold ones [67]. Second, peak prices often result in new and higher peak demands at different times (the so-called avalanche effect) [78], which can provoke new price peaks or grid congestions. Third, in some countries, the incentives are mitigated by volume-based levies, taxes, and network tariffs [4]. Adaptations in the design of the administrative price elements were discussed in section 3.3. Fourth, the reliability of the provided flexibility depends on the implemented control strategies, as explained in section 3.5.

Solutions for the latter also address the limitations of consumers and intermediaries. Intermediaries report a high integration effort compared to a small specific potential per asset [14]. Likewise for consumers, high social acceptability costs occur in the form of risk of welfare loss, price uncertainty, and monitoring effort [13,66]. Fatigue and rebound effects are observed, which decrease the provided flexibility in the medium term [65]. These limitations could be addressed by combining variable tariffs with automated load control [14].

Additional technological costs and limited control for the consumers need to be considered in this case. Also, it cannot access the flexibility provided by active changes in the daily routine (e.g., a postponed departure for a longer charging period of an electric vehicle), since the awareness and commitment of the consumer are required [14,23]. Field experiments test ToU more frequently than RTP and CPP. The experiments with CPP report the highest level of peak shifting but a limited shifted volume in total due to the rare peak times. The resulting low-cost saving leads to dissatisfied consumers. RTP and ToU lead to a similar level of peak shifting. The highest level is observed for experiments combining variable tariffs and automated load control [78].

All in all, the monitoring effort, price uncertainty, and communication cost for small and less reliable flexibility potential lead to high transaction costs compared to savings for the consumer. Especially in the case of rapidly changing tariffs, a combination with automated load control is recommended [23]. The acceptance of this combination depends on whether the transparency needs of the consumers are met with the targeted information at a low level of effort.

### 4.2. *Virtual power plant*

The design of VPP is characterized by aggregating electricity and flexibility for trading on the wholesale market (F1. A), which is directly enforced by the intermediary (F5. B). The consumer pays a trading fee and receives the trading revenue in return (F4. C). If locational information of the assets is provided, the VPP can participate in different congestion management mechanisms (F2).

The combinations of different technologies and locations in VPP portfolios create valuable electricity products that can be traded efficiently on the wholesale market [21,68]. Large portfolios in combination with a high fixed cost of forecasting and trading realize scale effects [7,83]. Direct control leads to increased reliability for the electricity system but limits the control for the consumers. VPP is mainly dedicated to generation assets, as well as flexible appliances, whose usage routine provides a predictable potential. To involve consumers with more intermittent usage routines, combinations of VPP and the local energy market are discussed [16].

All in all, VPP trades electricity and flexibility from distributed assets efficiently at a low level of transaction costs for the consumers. Thereby, it especially meets the requirements of profit-oriented consumers.

### 4.3. *Local energy markets with smart contracts*

The local energy market (F1. B) is combined with automatically executed contracts (F5. B) to enable local trading at a reasonable effort for the consumers. The automatically executed contracts take into account the preferences of the consumers, in particular the accepted price level, the origin of electricity, or the constraints for load shifting. The contract can be linked to smartphone apps for adapting preferences [16,81]. In the case of blockchain technology, the contracts are called smart contracts, which serve as a decentralized protocol for managing the interactions [16,80,84,85]. Also without blockchain technology, adaptable contracts are combined with trading on the local energy market [16,18,52,81,86].

Local energy markets are associated with peer-to-peer markets since their key design characteristics, consumers trading in geographical proximity with each other, are often combined [18,19,36]. Nevertheless, they are not congruent. Virtual peer-to-peer markets also exist on a larger scale than geographically proximate ones, allowing remote consumers to participate and enlarging the market [18]. Vice versa, the conditions of the local energy market may also allow commercial bidders or bidding consortiums, such as energy communities, to participate [18,81].

The main revenue streams in a local energy market are based on the consumers' willingness-to-pay for local electricity or remuneration for grid-friendly consumption. Concerning the latter, local dispatch automatically prevents the utilization of higher voltage levels [87,88]. As an inherent element of the bids, the locational reference also enables participation in congestion management mechanisms, such as flexibility markets and congestion pricing [16,53,89].

One design specification of a local market with the ability to be disconnected from the higher voltage levels is the microgrid [90,91]. The microgrid organizes investments in and the operation of grid infrastructure, generation, and flexibility sources in a way to balance demand and supply locally if needed. Their ability to manage intermittent renewables locally and act as a single, well-balanced entity increases the energy system's resilience [21,92]. In return, microgrids are exempt from paying grid tariffs and other administrative price elements if they are disconnected in moments of scarcity [32,93].

The willingness-to-pay for local electricity is discussed ambiguously in the literature [18,37,41,94]. While Rommel et al. [95] report a willingness-to-pay of up to 6.9 ct/kWh, Mengelkamp et al. [37] found a negative utility. Potential losses of living quality explain the negative utility due to the close proximity of the assets.

At the same time, the proximity of the intermediary in a local energy market coincides with knowledge about local conditions and trust, which is presented as an advantage for the activation of local assets [16,52,54]. Another trust-building characteristic is the local processing of data [18,38,39].

Little is known about the transaction costs involved, as most local energy markets are still underdoing research [18,86]. A high degree of automation in combination with smart contracts and smartphone apps, as well as risk management by the intermediary in the form of forecasting services and price caps are key design specifications for low transaction costs on the consumer side [54,94]. On the intermediary side, these services lead to high transaction costs, which need to be counterbalanced by scale effects [18]. If these challenges can be handled, the local energy market is a promising governance design for consumers with normative motivation and trust-building requirements.

### 4.4. *Energy community*

The energy community is the only governance design focusing on investments, in particular community-based investments (F6. B). It can be complemented by the previously presented design choices for operation. While the trust-building characteristics of the local energy market reinforce its community spirit, the VPP increases its cost-efficiency. Reciprocal effects are observed for combined investment and operation activities: Consumers co-owning renewable assets are more open to load shifting [34].

Two legal definitions exist on the EU level: the renewable energy community focusing on investments in renewables, and the citizen energy community involving all activities along the energy value chain. Both communities are voluntary, non-profit-oriented cooperation of natural persons, small businesses, and public administration, which enable joint investments in larger, more efficient assets at the most suitable locations [24].

The geographic scope ranges from buildings and neighborhoods to towns, and regions. Investment potential decreases with a smaller scope as does the coordination effort for defining the usage rights, investment, and operational costs in a contract between the participants [20,71]. For consumers owning or renting an apartment, energy communities at building level are especially attractive if they can then enjoy the self-consumption privileges of individual households (e.g., grid tariff or tax exemptions) [2]. Additionally, split incentive programs increase the attractiveness for tenants and landlords [24].

Renewable subsidy schemes, tax exemptions, and research projects have led to a rise in the number of energy communities over the last three decades [96]. In addition to active citizens and municipalities as first movers [97], most consumers state that they are interested in participation and willing to pay for it [41]. However, they are not willing to manage an energy community [42]. It is recommended to join forces with professionals to facilitate coordination and lower the transaction costs for consumers [6].

Such a professional approach still needs to be balanced with the social and sustainable objectives of the community. A targeted involvement of consumers is required to strengthen local democratic processes [22] and stimulate the activation of social norms and high trust capital [20].

## 5. Conclusions

In this paper, we presented a framework for systematically structuring possible designs for consumer governance in the electricity market based on the functions required to organize the electricity system-friendly operation of consumer-owned assets and the available design choices. The eight functions we identified concern, on the one hand, price signals (matching electricity and flexibility, congestion management, allocation of administrative price elements) and, on the other hand, consumers' response to them (pricing for consumers, operation of energy assets, investment in energy assets, data collection and billing).

Based on the inventory of functions and design choices, we categorized the numerous proposals in the literature and assessed the degree to which their benefits offset the induced transaction costs of consumers. This approach structures a large number of existing, partly overlapping research studies on consumer governance designs, which not only differ with respect to their design choices but also with respect to the consumer requirements they aim to meet. By bridging the fragmented research on different designs, their regulatory and contractual arrangements, and their performance, we are able to reveal the strengths and weaknesses of each design in a coherent manner and indicate pathways for their further development.

We identified four archetypes of governance design, which target the key trade-offs that consumers face when choosing a design. None of the designs performs all the functions required for organizing consumer response. The first archetype, energy communities, is characterized by the function of investing. Energy communities reduce investment barriers and increase trust capital.

The other three archetypes are characterized by the functions of matching and operating energy assets. Variable tariffs send price signals from the wholesale market to consumers so that they can adapt their energy assets themselves. They improve price transparency and consumers' control over their consumption. Local energy markets directly coordinate consumers' assets and trade them on their own geographically limited market. They ensure local value creation and data privacy. Virtual power plants also directly coordinate the assets and aggregate them for trading on the wholesale market. While the trust-building features of the first three archetypes primarily target normatively motivated consumers, the design of a virtual power plant is attractive to profit-oriented consumers due to its efficient aggregation.

The categorization reveals two shortcomings that require further research. With regard to the design, the archetypes can be combined with each other to cover any unspecified functions and provide comprehensive organizational support for active consumers. For instance, the electricity produced by the investments of an energy community can be traded in a two-stage trading process combining a local energy market and a virtual power plant to ensure an efficient electricity supply with local value creation. Further conceptualization and empirical research are needed to assess the performance and limitations of such combinations.

With regard to the attractiveness of the design, more empirical studies about the highlighted trade-offs are needed to confirm which archetype is suitable for which consumer type. This concerns, in particular, the acceptable degree of automated load control, considering consumers' need for control and data privacy.

## CRediT author statement

Sabine Pelka: Conceptualization, Methodology, Investigation, Visualization, Writing - Original Draft, Review & Editing. Emile Chappin: Conceptualization, Methodology, Writing – Review & Editing, Supervision. Marian Klobasa: Writing - Review & Editing, Supervision. Laurens de Vries: Conceptualization, Methodology, Writing – Review & Editing, Supervision.

## Declaration of competing interest

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

## Data availability

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

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