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Platform Services Facilitating the Participation of Active Households in the Energy System – a Transaction Cost Perspective

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***Abstract*— Platforms facilitate the participation of households and their energy assets in the energy system. Platform services are considered attractive for households if the energy cost savings exceed the transaction cost of the service. We conceptualize different platform architecture, quantify their transaction cost and compare it to potential energy cost savings from the literature. The design of its communication infrastructure especially influences the attractiveness of the platform architecture for two reasons. First, its other cost, particularly the platform core, accounts only for a minor cost share. Second, the grey and scientific literature discusses multiple communication infrastructure designs referring to smart metering. For the German case, two key design options, the certified and regulated advanced metering infrastructure and the agile Internet of Things based communication are combined into a third option to create a fully functional and certified infrastructure. This is the most attractive option for households deploying multiple flexibility sources or one large and predominantly controllable one (such as a heat pump).**

***Index* - Transaction Cost Economics, Smart Metering, Distributed Energy Resources, Energy Trading Platform, Intermediary**

I. Introduction

Households can flexibly consume electricity when owning heat pumps, electric vehicles, or white goods, such as dishwashers, washing machines, and dryers. However, it requires a great effort to make this potential accessible to the energy system [1, 2]. Service providers aim to decrease the effort by offering services [3]. In most cases, the services are organized on platforms to realize the scale and network effects [4]. The services are differently designed to meet the heterogeneous consumer requirements [5].

Transaction Cost Economics (TCE) by Williamson [6] defines this effort as transaction cost. It states that a service is only attractive if its benefits offset its transaction cost. The rise of platform services promises to realize the benefits of participation to minimal transaction cost compared to other services. While commercial products for the participation of industrial consumers exist (e.g., virtual power plants), research projects testing peer-to-peer markets, variable tariffs, and energy communities present promising services for households as well [7, 8].

Since the benefits of such services for households have already been explored in the literature, we focus on their transaction cost. This leads to our research question: "Which platform service induces transaction cost that is exceeded by the benefits of participating in the energy system?". In the following literature section, we present the key use cases for active consumers and link TCE to platform services. Based on this, the transaction cost elements for platform services are identified (section III) and compared to the use cases for cost-benefit analysis (section IV). In sections V and VI, the results are discussed and concluded.

II. Literature

A. Use Cases for Active Consumers

Households offer flexibility to the electricity system by shifting the consumption of their white goods, electric vehicles, or heat pumps (listed in increasing order of flexibility potential) [8–10]. The shift is steered by the price signals of the variable electricity tariffs [11–13]. Depending on the chosen service, the so-called active consumers monitor the price signals by themselves and shift the energy assets or allow the service provider to optimize and remotely control the assets on their behalf [14].

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The energy cost savings of active consumers is determined by a shiftable share of the electricity consumption and the price spread between the times of the formerly planned and the actual consumption. Most assets are shiftable during one day [15]. The consumption of heat pumps and white goods is assumed to be fully shiftable during that period. The average yearly consumption of white goods is 892 kWh [16] and ranges for heat pumps between 3,200 kWh and 3,800 kWh [9].

In contrast, the consumer's mobility needs constrain the shifting of an electric vehicle charging process. Depending on these constraints, electric vehicles' average yearly flexibility potential ranges between 2,000 and 2,907 kWh [13]. The literature reports for 2020, an average price spread of 10.1 ct/kWh for fully flexible assets such as heat pumps and white goods and 8.7 ct/kWh for electric vehicles [13].

The price spread and flexibility potential in the literature indicate energy cost savings for white goods of 89.20 EUR p.a., for an electric vehicle of 172 EUR p.a., and a heat pump of 350 EUR p.a.

B. *Transaction Cost Economics and Platforms in the Electricity System*

It is attractive for consumers to use a platform service if the benefits exceed the induced transaction cost. The level of the transaction cost increases with the frequency of interaction within the service, its uncertainty, and asset specificity. The latter is differentiated between physical assets required for the interaction (e.g., communication infrastructure) and human assets (e.g., energy know-how) [17, 18].

The scale and network effects of platforms promise to reduce the transaction cost of such services. In particular, a high degree of automation reduces the frequency of interaction for the consumer; the centralized load and price forecasting based on the platform data minimizes uncertainty and provides a consumer interface that does not require special knowledge on the side of the consumer [19].

The physical asset specificity is determined by the platform architecture, i.e., the design of the platform core and the communication infrastructure [20, 21]. The comprehensive smart meter rollout in the EU member states constitutes a key part of the future communication infrastructure. Depending on its progress, the functionality of meters, and the requirements of the active consumers, the regulated metering infrastructure is complemented with commercial technologies to perform the platform services. Based on the case of the German smart meter rollout, we demonstrate how different platform architectures and subsequent communication infrastructures realize the energy management to different transaction cost levels.

For the design of the platform architecture, the literature highlights two key design choices. First, the decision-making on the platforms can be organized centrally or decentrally. The decision-making approach often corresponds to electricity market design choices to integrate consumers. For instance, decentral decision-making enforced by blockchain technology is often combined with peer-to-peer markets [7].

In contrast, a central approach with one platform core for decision-making is often linked to the wholesale market and optimizes the participants in a hierarchical manner, such as virtual power plants [14]. At the same time, decentral, market-based, and central, hierarchical approaches can co-exist and reinforce each other [14, 22].

Concerning the second design choice, if platform operators are also the service providers, they could abuse their central role and restrict the access of other providers for exclusive access to consumers. This contradicts the idea of open platforms that realize the scale and network effects for their participants [4]. In the following analysis, we focus on centralized, open platforms with a platform operator that is unbundled from market participants.

III. Platform Architecture and its Transaction Cost Elements

The platform architecture consists of two parts: one is the central platform core responsible for forecasting prices and quantities, optimizing the trading strategy for the households, and facilitating necessary energy and business processes through energy and business-specific applications [20], and the other part is the decentral communication infrastructure enforcing the strategy and measuring its outcome [23, 24].

Comparing these two parts, we recognize two particularities in the literature. First, while a preferred design for the platform core exists [20], different design options for the communication infrastructure, in particular, the meters and communication gateways, are discussed depending on the status of the smart meter rollout. Second, the majority of the overall transaction cost accounts for the communication infrastructure.

In the following, we introduce the platform core and the communication infrastructure options, its fit to the use cases for active consumers, and its quantification. We differentiate the transaction cost between capital expenditure (CAPEX) and variable or fixed operational expenditure (OPEX). The presented information is based on systematic literature and web research and validated in semi-structured expert interviews.

A. *Platform core*

Description: The registration of an energy asset of multiple households and processing of their electricity data requires an open, big data ready, and secure platform core [20, 23]. These requirements are best met by a modular Internet of Things (IoT) platform with open and standardized protocols [25]. The characteristics support an easier integration of heterogeneous household assets compared to classical head-end systems. Typical modules of such an IoT platform core concern, on the one hand, the electricity data collection based on workflow and event engines, data lakes, and device and security management. On the other hand, the technical information is connected to commercial and technical processes, such as billing and enterprise resource planning software and a control system to coordinate operational parameters [20].

Application to use cases: The standardized interfaces allow a flexible extension of the IoT platform core with different applications and a communication infrastructure depending on the use case.

Quantification: Most service providers reflect CAPEX and OPEX of the platform core in fees for a platform-as-a-service product. This involves the cost for, e.g., operation and maintenance of the platform, its customizing, a control system, cyber security, and energy-related cost-to-serve. Based on the interviews, an payback period of five years, 100.000 participants per platform core, and an interest rate of 4.9 % [26], we calculate a yearly OPEX for operating one platform core of 30,000 EUR and a yearly CAPEX of 100,000 EUR.

B. Communication infrastructure option: Digital electrical meter and IoT gateway

Description: Platform operators complement regular digital meters with IoT gateways to make them remotely readable and household assets controllable. The gateway communicates with the platform core on the basis of its wide-area network interface, i.e., LoRaWAN. The digital meter can transmit meter data also directly over WAN or a LAN interface with the IoT gateway as an intermediary device. In this option, meter data is available in a 15-minute resolution.

Application to use cases: The German metering regulation (Messstellenbetriebsgesetz) requires the installation of certified smart meters for the load shifting of electric vehicles and heat pumps when they are available. Consequently, this commercial solution is only applicable to the load shifting of white goods.

Quantification: CAPEX of this infrastructure option are device costs of the IoT gateway and its installation as well as the implementation costs of the LAN or WAN capable digital meter. In this option, we assume no fixed OPEX. Variable OPEX can be yearly operation costs of the digital meter and communication and operation costs of the IoT gateway. Those variable OPEX depend on the number of devices. Based on the interviews, a payoff period of ten years for technical communication infrastructure, and an interest rate of 4.9 %, we found a yearly CAPEX of about 60 EUR and a variable yearly OPEX of 320 EUR.

C. Communication infrastructure option: Regulated advanced metering infrastructure (AMI)

Description: The German metering regulation and corresponding certification guidelines for cyber security (BSI TR-03109) define digital meters and their smart meter gateway that exchange the measured electricity data and control signals between the households and the platform core remotely. The smart meter gateway communicates with the platform core over WAN with sufficient bandwidth for larger overheads like cellular (GSM, LTE, 5G), PLC, or 450 Hz [12, 24]. According to the German regulation, the meter data must be distributed to all authorized market participants directly from the gateway. Household devices are connected via a home area network (HAN) interface and digital meters via a local metrological network (LMN) interface. Furthermore, the regulation specifies a controllable local system (CLS) interface that enables the direct control of assets over the gateway via a proxy server connected over WAN and the asset within the HAN. The CLS can also be used for the transmission of operational data to the platform core.

Application to use cases: According to the German regulation, households with a yearly consumption of more than 6.000 kWh, an electric vehicle, a heat pump and/or a generation capacity of more than 7 kW need to be equipped with AMI in the following years. The CLS of German AMI allows direct communication with all flexible assets in line with German cyber security regulations.

Quantification: The CAPEX consists of device costs, installation costs, and the costs of the construction of communication infrastructure. Fixed OPEX can be WAN provider costs. Variable OPEX can be the maintenance costs of devices, which depend on the number of devices, the cost of the operation and maintenance of the WAN communication infrastructure when using other technologies than existing cellular infrastructure, as well as the cost of the meter administration. The latter variable, OPEX depends on scale effects regarding the number of customers that use the AMI. We calculated CAPEX of about 390 EUR and OPEX of 130 EUR for the German-regulated AMI.

D. Communication infrastructure option: Regulated AMI and IoT gateway

Description: Since the rollout of smart meters with full functionality regarding safety and interoperability is still in progress in most EU member states (such as Germany), the missing functionalities of the smart meter gateways can be compensated by IoT gateways. This infrastructure option is, therefore, a combination of the first two options. It combines the smart meter gateway of the regulated AMI with an IoT gateway. While the IoT gateway enables the control of assets, the function of the regulated AMI lies in the correct processing of meter data and, subsequently, billing. As the regulated AMI is only needed for measurement and billing, we assume that today's available gateways can be used. Thus, the costs of the AMI part correspond to the price cap introduced by the German regulation authority.

Application to use cases: The combination of options B and C enables an agile, cost-efficient IoT communication on the basis of certified data for billing the electricity consumption, which is applicable for all flexible assets.

Quantification: As the regulated AMI is only needed for measurement and billing, we assume that today's available gateways can be used, and thus, the costs of the AMI part correspond to the price cap introduced by the German regulation authority. This price cap depends on the yearly consumption and can therefore be described as variable OPEX. Another variable OPEX is costs for communication and operation of the IoT gateway and devices. CAPEX can consist of device costs and installation costs. In contrast to option A, which can only be used for the management of white goods, this option can be used to also manage electric vehicles or heat pumps. Therefore, additional IoT devices are needed for the communication of the energy assets with the IoT gateway. Such bridges increase the CAPEX and OPEX regarding communication and operation. According to that, we calculated the yearly CAPEX ranging from about 90 EUR (white goods and BEV or heat pump) to about 140 EUR (white goods, BEV, and heat pump). The yearly OPEX ranges from 317 EUR to 352 EUR.

IV. COST-BENEFIT-ANALYSIS OF USE CASES FOR ACTIVE CONSUMERS BASED ON PLATFORM SERVICES

We compare the yearly transaction cost of the different platform architectures (section III) and the yearly energy cost

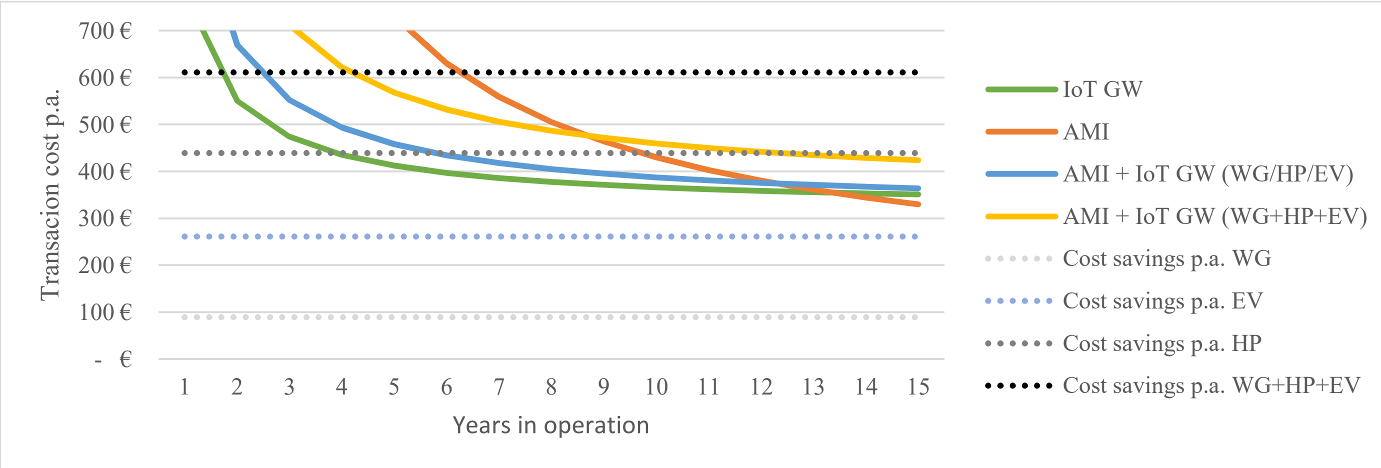

Figure 1: Transaction cost p.a. for IoT gateway (IoT GW), AMI and both combined (AMI +IoT GW for one devices or multiple), as well as potential cost savings p.a. per device (WG= white goods, EV = electric vehicles, HP = heat pumps)

savings of the use cases (section II.A) to assess which combination leads to a positive cost-benefit ratio (i.e., cost savings offset transaction costs). The results are presented in Figure 1.

While the variable cost for option III.D increases for every asset connected with a sensor, the other costs account mainly for the operation and maintenance of the architecture. Therefore, we calculate two cases for option III.D, the costs for the deployment of one asset and of all assets combined in one household. The CAPEX is divided into different years of operation, ranging from one to 15. Typical values for the lifetime of an electrical meter are 15 years and of a gateway ten years [27].

While the fully functional certified AMI (option III.C) has high CAPEX, the limited version complemented with IoT (option III.D) is driven by its OPEX per deployed asset. Comparing both options, the costs of the limited version are lower for the first 12 years for one deployed asset and eight years for all assets combined. Since this is close to the end of the technical lifetime, option III.D is the more attractive infrastructure option.

The cost of communication with only an IoT gateway (option III.B) is more attractive than the other two but less relevant since it is only allowed in combination with the load shifting of white goods. This combination is evaluated as unattractive since the low energy cost savings of white goods do not offset the transaction cost of option III.B. Also, the cost savings of energy management with an electric vehicle do not offset the transaction cost of options III.C or III.D.

In contrast, the load shifting with a heat pump results in a positive cost-benefit ratio in year 6 in combination with option III.D and in year 10 in combination with option III.C. Households with all assets (white goods, a heat pump, and electric vehicle) can realize a positive cost-benefit ratio in year 5 in combination with option III.D and in year 7 in combination with option III.C.

V. Discussion

A. *Decreasing communication infrastructure cost*

We demonstrated that the main driver of transaction costs is the communication infrastructure costs, which are subject to scale effects. For the CAPEX-dominated regulated AMI, the mandatory smart meter rollout has the potential to decrease device, certification, and administration costs, mostly over scale effects. On the other hand, the OPEX of infrastructure options with IoT gateways could also be lowered through scale effects in the use of existing or built communication infrastructure. It can be assumed that scale effects can have a higher impact on lowering costs at CAPEX-dominated options [28]. More users of the defined infrastructure option can lead to a decrease in costs through lower production costs of devices due to higher utilization of production capacity. In contrast, OPEX decrease through the bespoken scale effects can be partly compensated by the need for more server equipment and a more powerful core architecture layout.

Although, the specificity of the German energy market and energy markets, in particular, needs to be taken into account. IoT solutions of established global data companies could be less cost-intensive than the regulated German AMI. But based on the analyses of Klobasa *et al.* [19] and Küfeglu *et al.* [29], which evaluated various platform services in the energy sector, a non-negligible amount of smaller service providers can be identified. Those solutions are tailored for the use cases in the energy sector but are usually more expensive due to missing scale effects. A higher customization and development effort that could be needed for the products of global data companies could potentially offset the cost difference. The comparison of different solutions providers is identified as a subject of further research to identify cost differences over energy-related requirements.

B. *Number of platform participants and its effect on platform core costs*

Even if the assumed participant number of 100,000 for each platform is increased and, therefore, the specific platform core cost per participant decreases, the small share of the platform core on the overall cost does only marginally impact the cost-benefit ratio.

C. Regulated metering prices and HEM as alternatives

Higher costs than defined in the German metering regulation as yearly price caps for smart meters are listed for a fully functional AMI in option III.C. If the full functionality is provided to the regulated price caps in the future, more use cases (e.g., with electric vehicles) will become attractive.

Prospectively, home energy management systems can be further developed with IoT gateways to offer optimization services. If the forecasted initial investment cost of 2,000 EUR remains on the same level [30], this service will lead to a positive cost-benefit ratio after 4 to 8 years, depending on the use case). Such commercial alternatives need to be aligned with national regulations and market design.

D. Grid services provided by households and increasing electricity prices

The flexibility of household assets can be applied to prevent distributed grid constraints as another use case. Mechanisms, such as the flexibility market, are currently under discussion. Established grid-based incentives in the form of variable tariffs in Germany are around 70 percent higher than market-based incentives [31]. Even for the less flexible electric vehicles, such a revenue stream covers the cost of option III.D after four and III.C after eight years.

Also, the drastically increased electricity prices in 2022 would also change the attractiveness of the platform services. In March 2022, two times higher price spreads than applied in the cost-benefit analysis are monitored on average [32]. With such a price spread, the use cases with the combined assets and a heap pump show a positive cost-benefit ratio in year two, and with an electric vehicle in year four for option III.D, the more cost-intense option III.C in year three, five, and eight respectively.

VI. Conclusion

Platforms facilitate the participation of households and their assets in the energy system. Since the cost share of the platform core is neglectable respecting the overall cost, the design of the communication infrastructure mainly impacts the attractiveness of the households. While the commercial IoT-based communication is driven by OPEX, the high CAPEX share of regulated AMI presents a substantial entrance barrier for households.

Once a fully functional communication infrastructure based on the regulation AMI can be provided to the aspired regulated price cap, the participation becomes attractive to a broader range of households in Germany.

Till then, its complementation with IoT bridges the missing functionalities to a reasonable cost for households deploying multiple flexibility sources or one large and predominantly controllable one (such as a heat pump). We recommend to further research on the scale effects of the transaction cost depending on the competition of operators, the revenue streams of grid services, as well as the impact of empowering and tailored platform services on the households' motivation for energy management.

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