Economic feasibility of low-voltage demand side response aggregation on the Czech electricity market

Master's thesis

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FACULTY OF
ELECTRICAL
ENGINEERING

ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Studijní program: **Elektrotechnika, energetika a management**
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II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Ekonomická realizovatelnost agregace na hladině nízkeho napětí

Název diplomové práce anglicky:

Economic feasibility of aggregation on low voltage level

Pokyny pro vypracování:

1. Proveďte rešerši na současnou a předpokládanou pozici nezávislého agregátora flexibility na straně poptávky na nízkém napětí pro poskytování služeb výkonové rovnováhy v budoucí decentralizované a dekarbonizované elektrizační soustavě
2. Definujte typické příklady použití flexibility na straně poptávky na nízkém napětí, včetně odhadu potenciálu pro jednotlivé příklady
3. Kvantifikujte možné rozsahy poplatků za nabízenou flexibilitu pro jednotlivé příklady poskytovatelů flexibility
4. Potvrďte relevantnost těchto poplatků skrz focus group a kvantitativní výzkum v současné české populaci a případně zjistěte další motivace pro poskytování flexibility mimo čistě ekonomické

Seznam doporučené literatury:

IRENA. Aggregators. Innovation Landscape Brief. 2019b
Eurelectric: Designing fair and equitable market rules for demand response aggregation
Selina Kerscher, Pablo Arboleya: The key role of aggregators in the energy transition under the latest European regulatory framework

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My gratitude belongs to the ČEPS Digitization office for investing their time and resources into this work and sharing their deep knowledge and passion for demand side response flexibility. I would like to also thank to NMS Market Research agency for applying their market research expertise in eliciting consumer responses and collecting the data on relevancy of this work. Last but not least, my wife deserves appreciation for putting up with my studies and my parents deserves my gratitude for always sharing their practical insights.

Author statement for graduate thesis

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the Methodical instructions for observing the ethical principles in the preparation of university theses.

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V Praze dne . . . .

Podpis autora

Abstract

With gradual decarbonization and phase out of fossil fuel power plants from the Czech power grid, new sources of ancillary services need to be introduced to fill in the gap. This thesis estimates economic feasibility of low-voltage demand side response aggregation for ancillary services. Dispatchable low-voltage devices represent a significant portion of the power grid demand, especially in the winter months. I calculated the flexibility potential for average dispatchable devices in the Czech grid and consequently estimated monthly fees available to typical device owners that would offer their devices to an aggregator to participate in ancillary services. I tested relevancy of these fees in a quantitative survey with a representative sample of the Czech population with 2,538 respondents. I also identified and quantified the main motivators and barriers to participate. Over 50% of eligible respondents were interested to participate in such flexibility offering, representing a potentially large pool of flexibility for the future ancillary services providers.

Key words

Aggregator, ancillary services, low-voltage flexibility, demand side response

Abstrakt

S postupnou dekarbonizací a odstavováním elektráren na fosilní paliva z české elektrifikační soustavy bude nutné uvést do soustavy nové zdroje podpůrných služeb, které nahradí odstavené elektrárny. V této práci jsem se zabýval ekonomickou realizovatelností využití odezvy na straně poptávky na nízkém napětí pro podpůrné služby. Řiditelná elektrická zařízení na nízkém napětí tvoří velkou část poptávky po elektřině, obzvláště v zimních měsících. V této práci jsem spočítal potenciál flexibility pro průměrné řiditelné elektrické zařízení v české soustavě a následně jsem stanovil velikost měsíčních odměn vlastníkům za nabídnutí svých zařízení agregátorovi pro zařazení do podpůrných služeb. Relevantnost těchto odměn jsem otestoval na reprezentativním vzorku české populace s 2 538 respondenty. Identifikoval jsem hlavní motivátory a bariéry a zhodnotil jejich důležitost. Přes 50 % respondentů splňujících podmínky účasti by mělo zájem poskytnout své zařízení agregátorovi, což představuje potenciálně veliké množství flexibility pro budoucí poskytovatele podpůrných služeb.

Klíčová slova

Agregátor, podpůrné služby, flexibilita na nízkém napětí, odezva na straně poptávky

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List of Abbreviations

aFRR	automatic Frequency Restoration Reserve
B2C	Business to Customer
BRP	Balance Responsible Party
CHP	Combined Heat and Power
DSO	Distribution System Operator
DSR	Demand Side Response
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EEX	European Energy Exchange
ERÚ	Czech Energy Regulation Office (Energetický Regulační Úřad)
EV	Electrical Vehicles
FCAS	Frequency Control Ancillary Services
FCR	Frequency Containment Reserve
HDO	Ripple control (Hromadné Dálkové Ovládání)
HV	High Voltage
LV	Low Voltage
mFRR	manual Frequency Restoration Reserve
MV	Medium Voltage
NAP SG	National Action Plan for Smart Grids
OEM	Original Equipment Manufacturer
OTE	Czech electricity and gas market operator (Operátor Trhu s Elektřinou)
RR	Replacement Reserve
TDD	Synthetic Load Profiles (Typové Diagramy Dodávek)
TSO	Transmission System Operator
V2G	Vehicle to Grid

List of annexes

Annex 1 – Survey form (in Czech only)

Annex 2 – Excel model for flexibility and fee size estimation

All annexes are submitted only in the electronic format.

I. Introduction

Growing penetration of renewables in the European electricity market together with decarbonization pressure lowers prevalence of the traditional large power plants active in the grid. However, exactly these large power plants provide most of the ancillary services to the Transmission System Operators (TSOs) through the energy stored in their large rotating masses. Without these power plants, more flexibility will be required from other electricity market players. This may include renewables such as solar or wind power plants, smaller combined heat and power (CHPs) plants, large-scale battery storages, industrial demand side response (DSR) or demand side response from the low-voltage (LV) commercial and residential appliances such as heat pumps, electrical heating, or cooling (Villar et al., 2018). Yet many of these energy market players, at least all the low-voltage ones, are too small to effectively participate in providing flexibility services to the TSOs.

To enable such participation of these sub-scale players, aggregators have emerged to act as a medium layer between these participants and the TSOs (Correa-Florez et al., 2020). While integrated aggregators are already established in the Czech regulatory environment and present in the Czech energy market, EU mandates its member states to introduce independent aggregators as well. These entities can provide flexibility on the ancillary services or wholesale energy markets but are not responsible for the imbalance this flexibility causes to the energy supplier of the customers whose demand is altered by the independent aggregator. These new independent aggregators should bring more competition and creativity to the aggregation market, leading to lower prices for the TSOs, and hence for the electricity consumers, better renumeration for the flexibility providers, and possibly faster inclusion of LV devices.

Several studies have been carried out on ability of aggregators to provide ancillary services, mostly by TSOs in Western Europe such as TenneT. These studies mostly confirmed aggregators' ability to provide ancillary services to TSOs at the required quality, despite several technical challenges mainly in data collection and storage, communication, and sometimes in the guaranteed reliability (TenneT, 2018; TenneT, 2021). At the same time, other studies have confirmed the sizeable theoretical potential of the different sub-scale technologies to provide flexibility in the Czech market (NAP SG, 2018). Among the DSR options, low-voltage DSR for space heating and water heating has the overall largest flexibility potential. Even though part of that flexibility is already captured via the existing two-tier tariff schemes, traditionally prevalent among the Czech customers and administered via ripple control (HDO), this segment has large potential to provide ancillary services with fast reaction time.

Independent aggregators will likely be those to tap into this segment which entails more complexity than aggregation of CHP plants or large industrial or commercial players which are already being onboarded to participate in the Czech ancillary services market via existing integrated aggregators. Even though the short-term focus should be naturally placed on successful integration of these medium-voltage players in the market, with deeper decarbonization the low-voltage players may become soon economically and technically relevant flexibility players. Even the International Energy Agency has declared that recent developments “underline the case for diversifying and expanding DSR to smaller loads and other sectors, including transport and heating” (IEA, 2020).

This thesis aims to define conditions under which aggregating a low-voltage demand side response is economically feasible for the involved parties. Such ‘business case’ includes current pricing of the ancillary services and its future outlook, and other monetization options such as wholesale market bidding, unitary capex at flexibility providers, capex and opex overhead costs, and renumeration schemes that would motivate individual low-voltage players to offer flexibility to the aggregator. This thesis focuses on the currently most promising low-voltage technologies such as space heating, water heating, electric vehicles, and batteries. Even though some of the technologies might not be economically promising at the moment, with ancillary prices increases and economies of scale in aggregation, the business case might soon become more financially interesting for both the aggregators and the low-voltage flexibility providers.

This thesis focuses on the low-voltage business cases and will not address the other outstanding problems related to introduction of independent aggregators to the Czech energy market, such as regulatory position of independent aggregators, methods for setting up baseline, and rebound effects accounting. In case lack of clarity in some of these barriers influences the business case, assumption is taken on the most likely outcome.

The rest of this thesis is structured as follows. Section II describes the status of the Czech ancillary market, concept of aggregators, and expected potential of low-voltage demand side response. Section III calculates the size of flexibility potential for individual priority LV devices. Section IV presents the methodology of the business case for individual devices. Sections V discusses the renumeration, i.e., “profit” from participating in the flexibility offering. Finally, Section VI presents outcome of the qualitative and quantitative research on relevancy of such renumeration.

II. Low-voltage independent aggregator market description

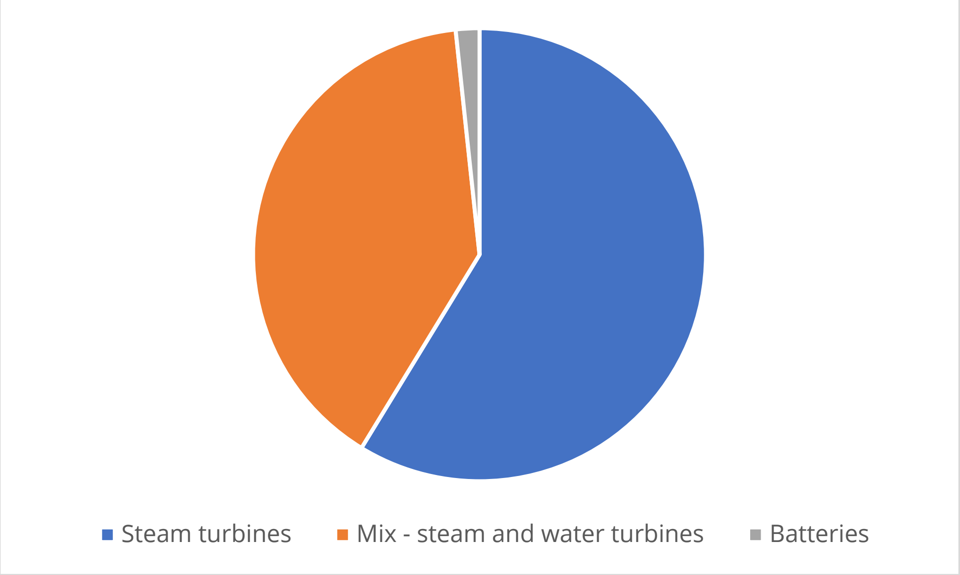
a. Czech ancillary services market

Ancillary services represent a set of offers by private energy market players to adjust its power supply or power demand under the instruction of the TSO to help to balance the grid. Similarly to other electricity markets, the Czech ancillary services market has been traditionally provided and still is provided by synchronous generators of the large coal, gas, water or nuclear power plants and gas or coal CHPs as illustrated in Figure 1. As the large fossil fuelled power plants will play less and less important role with ongoing decarbonization, the TSO will not be able to rely on them to provide the ancillary services at the current extent. On top, higher penetration of the weather-dependent intermittent sources will likely increase demand for frequency control ancillary services (IRENA, 2019). New providers may and will include hybrid renewable plants, demand side response on large industrial plants or commercial buildings as well as low-voltage residential appliances.

Table 1 shows the 2018 prediction of energy potential used for positive flexibility for ancillary services in the Czech grid. The gradual exit of the large power sources is partially compensated by growth in the combined heat and power plants. However, the exit of the large power sources might be much faster given the recent announcements of stricter decarbonization targets and faster coal phase out.

Batteries are the only new technology currently providing at least small portion of the ancillary services in the Czech Republic. For example, ČEZ has successfully completed an ancillary services pilot of 4 MW / 2.8MWh battery in conjunction with an existing 200 MW steam turbine already certified to provide ancillary services in 2021 (ČEZ, 2021). Similarly, C-Energy operates its 4 MW / 2.5 MWh battery along with existing gas power plant to provide ancillary services. On top, 0.5% of the volume of the ancillary services auctioned for 2022 is already provided by an aggregator which pulls together 30-40 existing sub-scale hydro and CHP plants (E.ON, 2021). However, these are still minor volumes relative to the need of the market.

Figure 1. **Ancillary services providers shares in 2022 ČEPS bids by type**



Source: ČEPS, 2021

Table 1. **Positive flexibility sources forecast**, MW

Positive flexibility source	**2020**	**2030**	**2040**
HV power sources >10MW except for solar and wind	850	770	690
MV power sources >10MW except for solar and wind	155	140	130
CHP plants	60	110	170
Small hydro plants	5	10	20
Biogas stations	---	---	---
Biomass sources	---	---	---
Wind plants	---	---	---
Solar	---	---	---
Micro combined heat and power plants	---	10	20
Total	**1,070**	**1,040**	**1,030**

Source: NAP SG, 2018 (b)

In line with the European standards, ČEPS has restructured its frequency control ancillary services (FCAS) from April 2019. The currently used FCAS are below (ČEPS, 2021):

- Frequency Containment Reserve (FCR): local autonomous reserve service operated in a decentralized manner at each of the FCR providers. Balancing energy is not evaluated. The bid sizing is from 1 to 10 MW.
- automatic Frequency Restoration Reserve (aFRR): reserve automatically managed by the system. Balancing energy is recorded and renumerated. The bid sizing is from 1 to 70 MW.
- manual Frequency Restoration Reserve in 5/15 minutes (mFRR5/mFRR15): reserve manually managed by the TSO with start-up times of either 5 or 15 minutes by which time the providers need to deliver the full agreed power output. Balancing energy is recorded and renumerated. The bid sizing is from 1 to 99 MW.
- Replacement Reserves (RR): reserve manually managed TSO with startup times of 30 minutes. RR is not reserved in advance and hence only balancing energy is renumerated, not reserved capacity.

Studies published by TenneT, a large Western European TSO, have confirmed aggregators' ability to provide ancillary services via flexibility to TSOs (TenneT, 2018; TenneT, 2021). TenneT has tested several device types by different aggregators for FCR and aFRR ancillary services. By extension, aggregators should be able to provide as well the mFRR service which has lower requirements on speed and autonomous behaviour than FCR or aFRR.

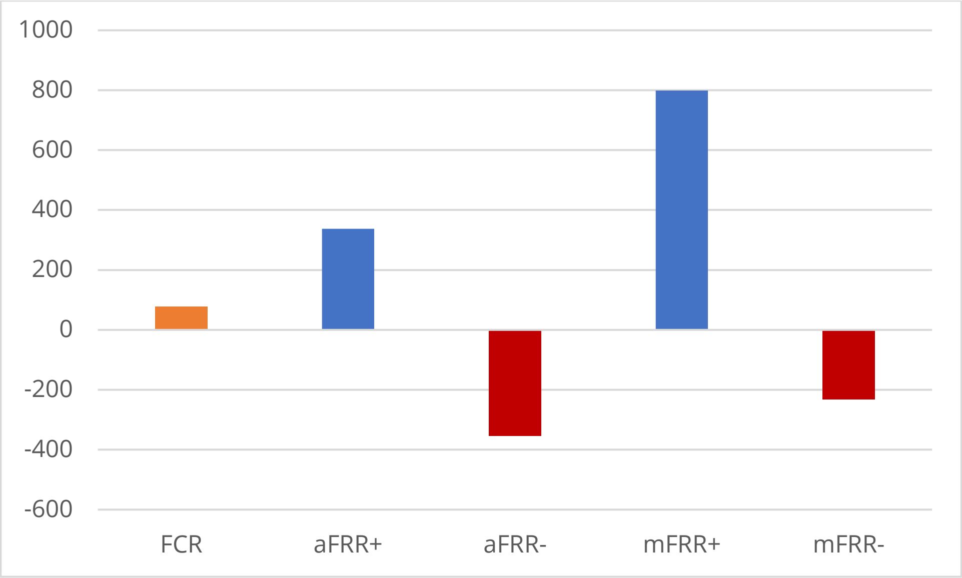
The non-frequency ancillary services such as secondary regulation of U/Q or black start services, are not considered in this thesis as they cannot be typically provided by demand side response activities. Similarly, I do not include any analysis of the RR ancillary services as its volume and value is currently marginal (OTE, 2021).

We recognize two directions of flexibility: positive and negative. Positive represents increase in power output or reduction in power demand. Conversely, negative flexibility represents decrease in power output or increase in power demand. Positive flexibility is in general more valuable than negative flexibility which can be relatively accessible. At the 2022 bidding prices, bids for mFRR15+ were on average 3 times more expensive than prices for mFRR15- (ČEPS, 2021c). TSOs are interested in receiving all the types of the ancillary services the LV aggregators can offer. However, in this analysis I assume the slow-response negative flexibility, mFRR-, will have competitive offering from other providers at lower costs than LV aggregators. Any renewable plants operating on at least partially market-based pricing will be at the time of high electricity supply and hence low electricity prices happy to be paid for curtailment, which is technically relatively easy to perform, if paid more than the current electricity price for the curtailed energy. I also exclude FCR in this work as extremely quick reaction times required might be difficult to achieve for highly decentralized LV devices.

Similarly to other European energy market, a provider of ancillary services is rewarded in two ways. Firstly, he/she receives a fee for each MW reserved for ancillary services that the TSO can tap into in case of system imbalance. Secondly, he/she receives a fee for each activated MWh of balancing energy when the system imbalance occurs. Nowadays, roughly 70% of the frequency control ancillary services ČEPS procures on long-term contracts while the remainder is procured in day-ahead market.

The amount of FCAS procured each year is defined by the Grid code (ČEPS, 2021). TSO is mandated to maintain ancillary services to cover system imbalance in 99% of time while at the same time maintaining the N-1 rule, i.e., ability to maintain the grid stability after losing supply or demand from any facility connected to the grid. In case of the Czech grid, this means ability to offset tripping of one of the units of nuclear power plant Temelín worth 1,080 MW. The volume split of frequency ancillary services procured by ČEPS in 2020 is presented in Figure 2. The FCR amounts to 80 MW while the positive ancillary services (aFRR+, mFRR+) and negative ancillary services (aFRR-, mFRR-) amount to 1,140 MW and 585 MW, respectively.

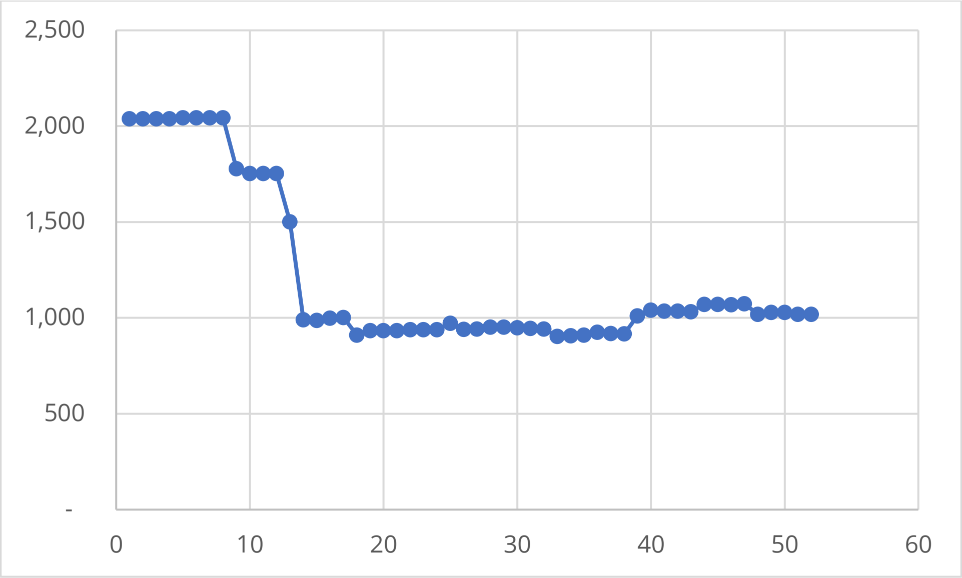
Figure 2. **Volume of ancillary services procured by ČEPS in 2020**, MW



Source: ENTSO-E, 2022

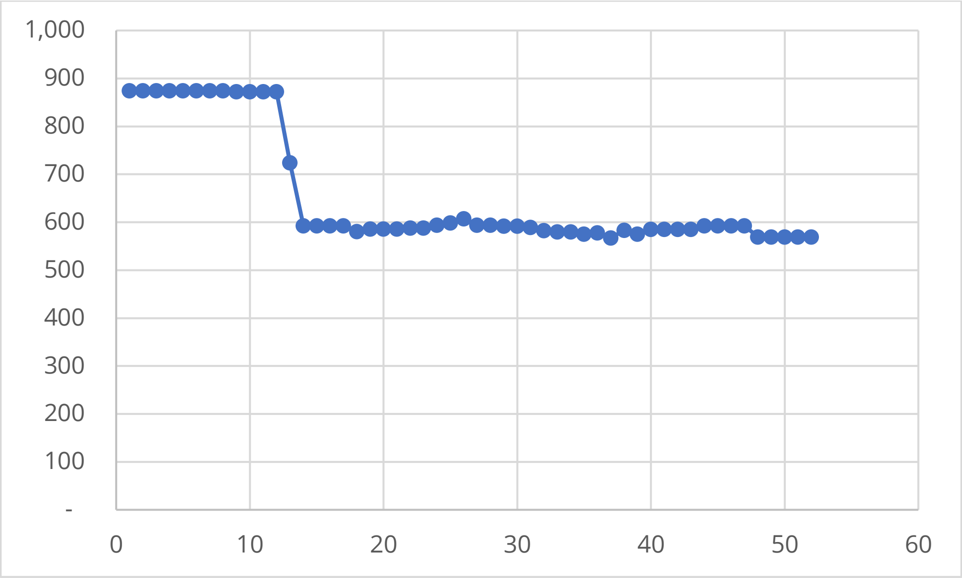
There a is large variability in prices of the FCAS for different types as well as for different years and weeks. Prices of ancillary services procured on the long-term market are reported by ČEPS as weekly averages (ČEPS, 2021c). The prices for the different type of FCAS exhibit quite large variability between months, linked to the availability of power plant units to provide these services. Figure 3, Figure 4, and Figure 5 present long-term contract prices for the main positive FCAS procured for 2022. Winter months display higher prices than summer months in 2022. Overall, ČEPS has spent 6,435 million CZK just in 2020 for ancillary services (ČEPS, 2021d). The prices for the day-ahead ancillary services, currently representing 30% of the total volume, are not publicly available. In general, these tend to be up to 100% higher than the long-term contracts. However, without official data I do not rely on this general perception and use only the long-term data for calculation. Further motivation not to use day-ahead data is discussed in the Section IV.

Figure 3. **Weekly average prices of ancillary service in 2022, aFRR+**, CZK/MW



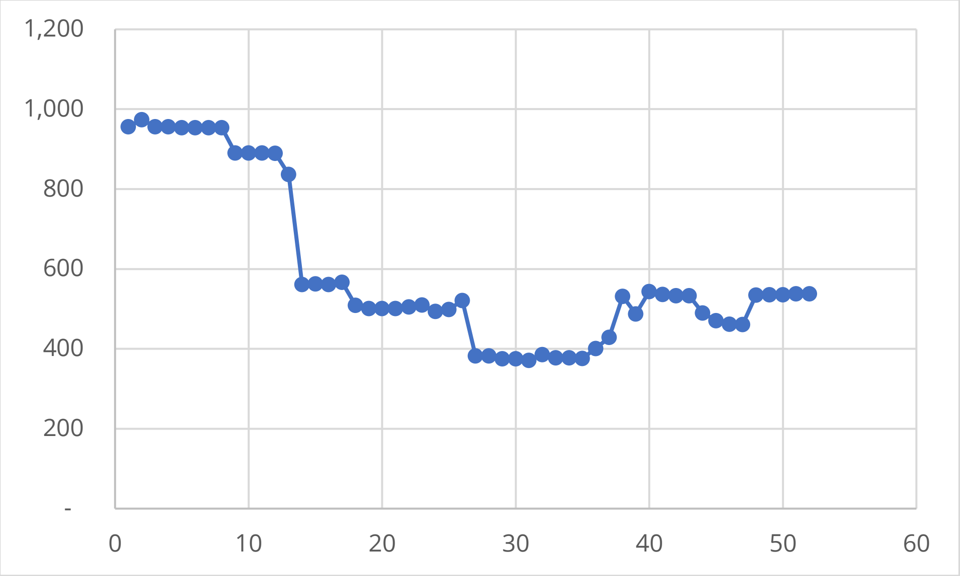
Source: ČEPS, 2021c

Figure 4. **Weekly average prices of ancillary service in 2022, mFRR5**, CZK/MW



Source: ČEPS, 2021c

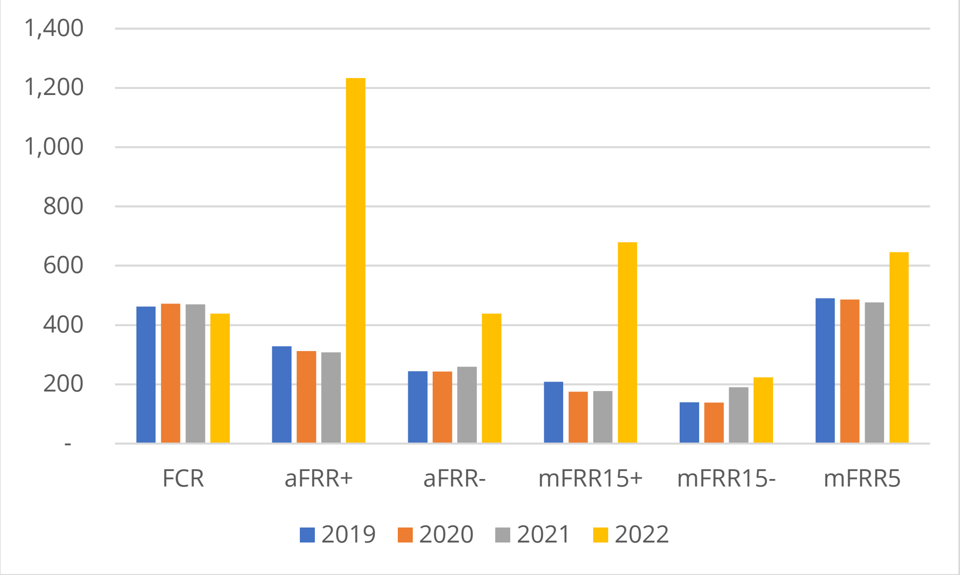
Figure 5. **Weekly average prices of ancillary service in 2022, mFRR15+**, CZK/MW



Source: ČEPS, 2021c

Long-term contract prices of the FCAS have been stable before 2021 but grew significantly for 2022, especially for the aFRR+ and mFRR15+ services, which are exactly those potentially offered by the LV DSR. The price development is illustrated in Figure 6. The spike in 2022 is likely due to the industry-wide price increase of energy resources, especially gas which is used by many of the Czech ancillary services providers. For my analysis, I am using the most recent 2022 data which are likely the best representant of any future prices.

Figure 6. **Frequency control ancillary services prices development**, CZK/MW

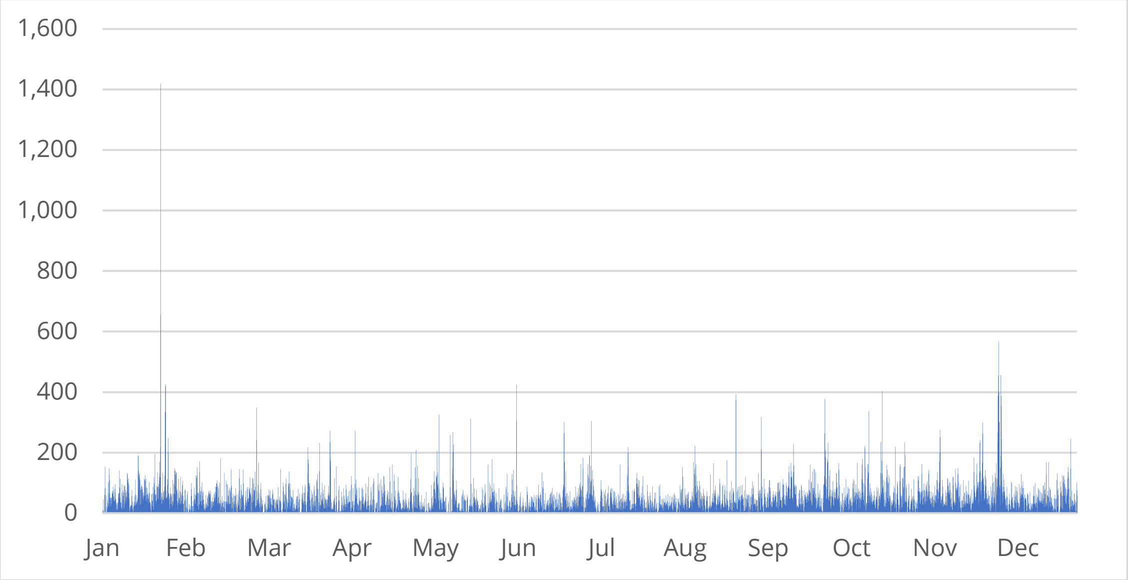


Source: ČEPS, 2021c

Ancillary services currently represent only small portion of the electricity bill. In the October 2021 retail price list of the Czech incumbent energy supplier ČEZ Prodej (2021), ancillary services are priced at 113 CZK/MWh for retail energy consumption, which represents just 1.5% of the total fee per MWh for a typical retail customer. This is quite low and increasing this fee to guarantee stability of the grid is likely to be defendable if other options at lower price will not be present. Even tripling the current ancillary services fee to 339 CZK / MWh would increase the overall electricity price by only 3% which seems marginal relative to the large swings in the electricity prices during 2021.

The volume of activated balancing energy is tracked by OTE, the Czech electricity market operator. The positive activated balancing energy in 2020 amounted to 269 GWh. There is naturally large variability between hours depending on the stress on the grid. While many hours in the year did not require activation of any positive balancing energy, the average hour used 32 MWh of positive balancing energy. The maximum of 1,419 MWh of activated positive balancing energy occurred at 6pm on 22nd of January 2020. Hourly data are presented in Figure 7.

Figure 7. **Hourly volume of positive balancing energy activated by ČEPS in 2020**, MWh



Source: OTE, 2020

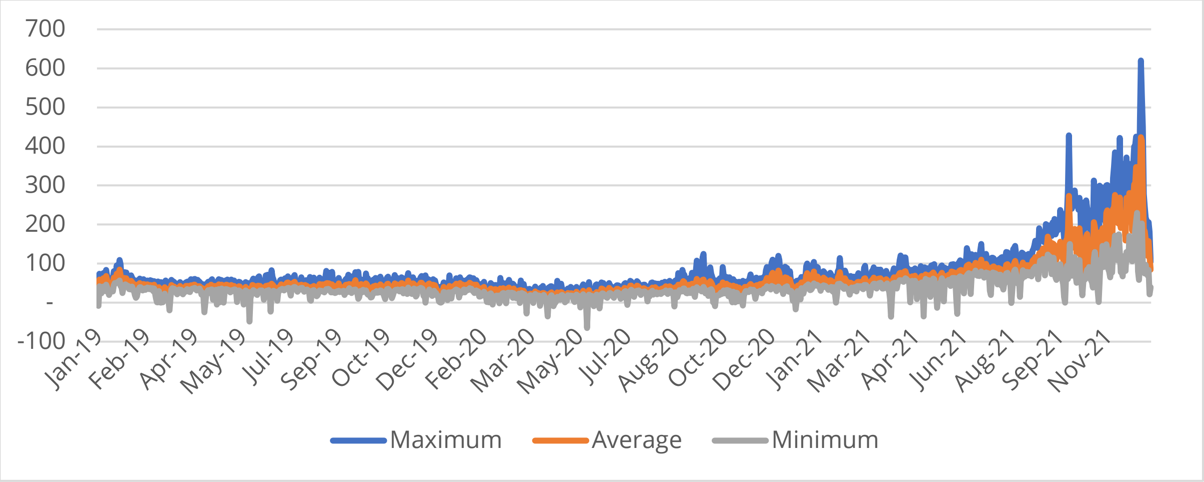
Price of the positive balancing energy is prescribed by the Czech regulator ERÚ and is driven by offer prices of electricity on the units offering ancillary services. In both 2020 and 2021 the prices remained stable around 2,400 CZK/MWh (99 EUR/MWh).

Together with several other private and public players, ČEPS has already started research on demand side response flexibility aggregation in the Czech electricity system. Most of research is orchestrated through the National Action Plan on Smart Grids (NAP SG) which brings together the key stakeholders in the Czech energy transformation and allocates research studies. The most relevant studies for low-voltage DSR aggregation are DFlex and SecureFlex. Project DFlex is aspiring to set up proper legislative framework for aggregators, confirm certification requirements, define baseline calculations and data communication requirements. Project SecureFlex defines conditions and limitations to providers of flexibility to prevent any potential energy security risks. Both projects are ongoing, and their outputs are gradually implemented into legislation and regulation.

b. Czech wholesale electricity market

Czech wholesale electricity prices, traded at the Leipzig European Energy Exchange (EEX), are highly correlated with the German wholesale prices. At the time of peak prices, aggregator may choose to activate its DSR flexibility providers to reduce their demand and in essence sell negative consumption on the market. Benefits of using DSR are said to gradually move from ancillary services to wholesale market, which has recently experienced large variance in spot prices (oEnergetice, 2018). Spikes in power prices on the EEX create more space for aggregators as with higher overall price level, the extremes also tend to be higher, as visible in Figure 8.

Figure 8. **EEX CZ wholesale electricity prices (day-ahead)**, EUR/MWh



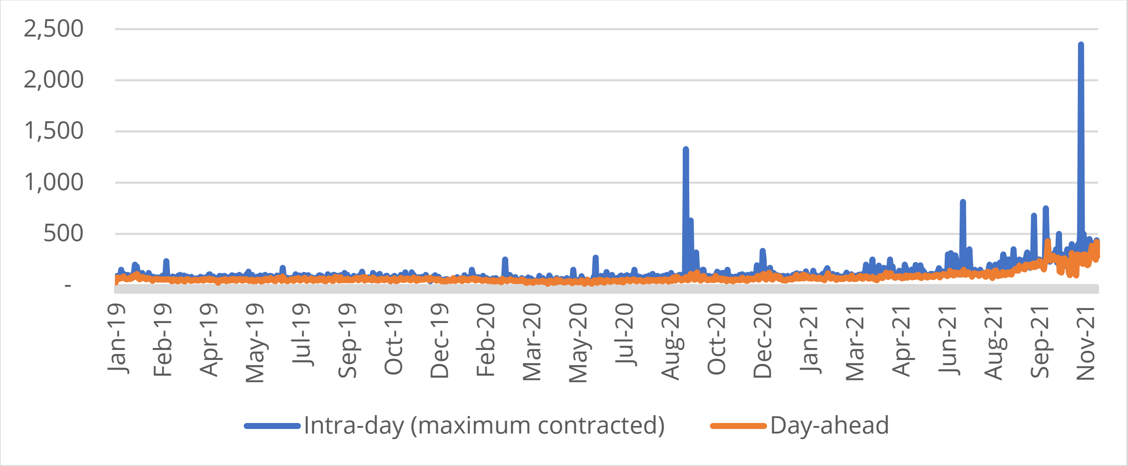
Source: EEX, 2022

For further analysis, I split this data into two sections: before September 2021 and after September 2021. While the average daily maximum between January 2019 and August 2021 was 60.4 EUR / MWh, the average daily maximum between September 2021 and December 2021 was 246 EUR / MWh. While in the first period the hourly maximum never surpassed 400 EUR / MWh, in the second period this occurred on 57 occasions. These are exactly the extreme numbers where DSR might be a relevant technology for the wholesale market.

Aggregator can also offer its negative consumption on the intra-day market, which is commonly used to clear emergency situations and hence should present higher variability. Unlike day-ahead market, intra-day market is not cleared by single hourly price, but instead separate contracts exist with different prices. This means we can analyse the extreme cases from two perspectives: the highest prices contracted in given hour and the weighted hourly price by contracted volume. Figure 9 and Figure 10 present the comparison with the day-ahead daily maximums from both perspectives.

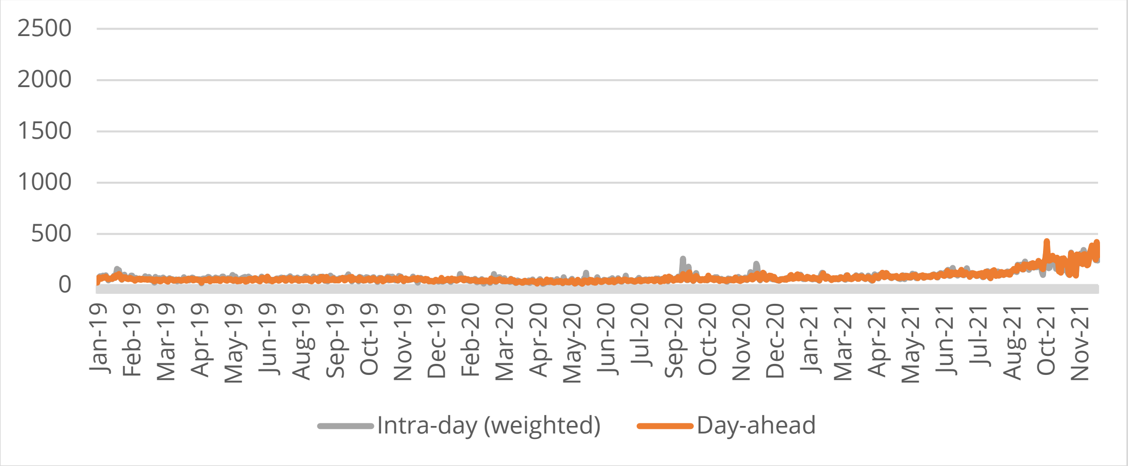
Comparison with highest prices contracted confirms the notion of much higher variability of the intra-day prices with several extreme cases of prices above 1,000 EUR/MWh. Even though not common, these are exactly events where DSR aggregator can play a role. Also, unlike day-ahead market, big variability and extreme cases occurred even outside of the period of high prices from September 2021. On the other hand, comparison with the weighted prices does show minimal difference to the day-ahead market. This indicates that even though there are cases of extreme prices, their volume is too low to influence overall weighted market price and so present a relevant difference to day-ahead market for an aggregator.

Figure 9. **Comparison of daily maximum prices on the EEX CZ power market – maximum**, EUR/MWh



Source: OTE, 2021

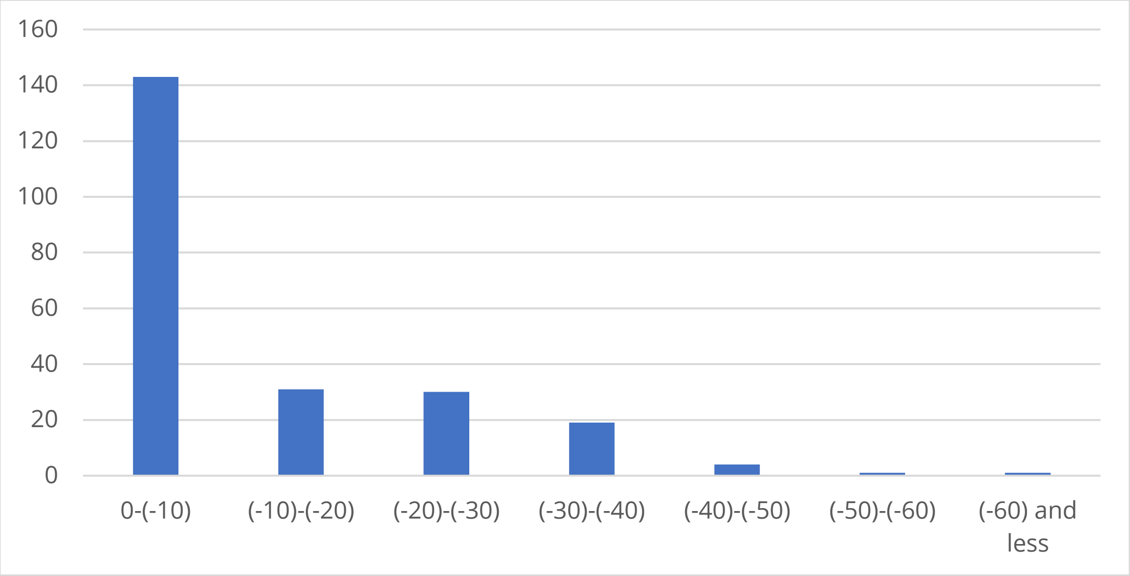
Figure 10. **Comparison of daily maximum prices on the EEX CZ power market – weighted**, EUR/MWh



Source: OTE, 2021

With growing penetration of renewables, negative prices started to occur relatively frequently at the time of high renewables output and small demand. DSR flexibility providers might function as a good power discharge tool – increasing power consumption for heating can be always easily compensated by more frequent ventilation without much customer discomfort, creating a further business opportunity for the aggregator. Looking at the day-ahead data, all of the negative price events occurred during the low energy prices between January 2019 and August 2021. Overall, there were 229 negative price events, most of which with small negative prices between 0 and -10 EUR/MWh. Still, there were 25 events with more than -30 EUR/MWh, presenting opportunity for DSR aggregators. Figure 11 illustrates the distribution.

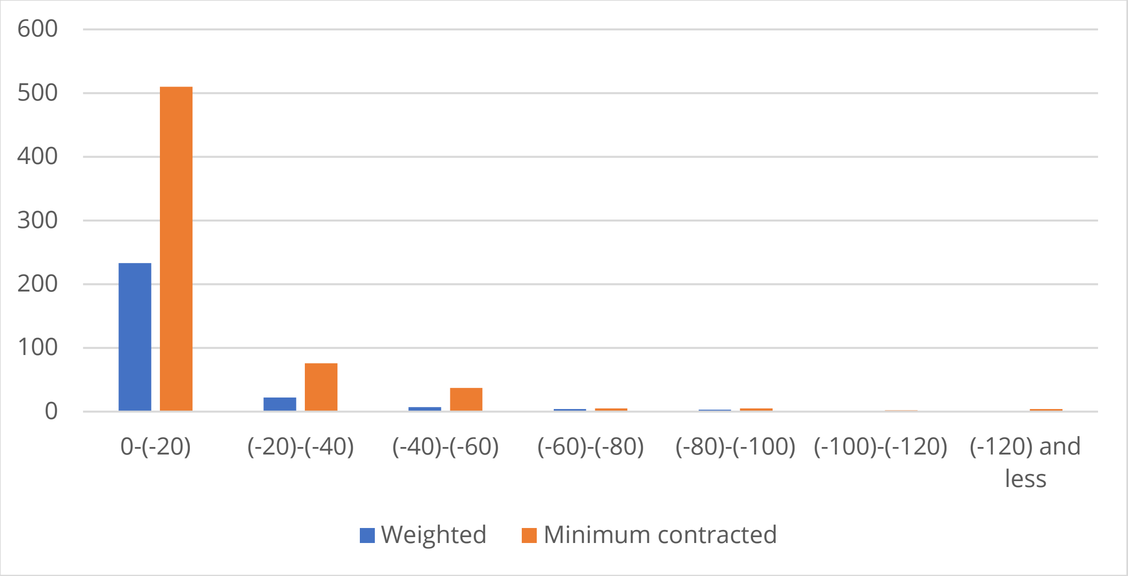
Figure 11. **Histogram of occurrences of negative prices on the EEX CZ day-ahead market**, EUR/MWh



Source: EEX, 2022. Authors own calculations

Intra-day negative prices show similar mechanism as the positive intra-day prices. If looking at the minimum contracted price, there are several very high negative numbers below -100 EUR / MWh, as seen in Figure 12. However, when applying the more appropriate weighted price, these frequent extreme negative prices disappear. This again indicates to the fact that these extreme negative prices are traded in very small volumes and are unlikely to present a relevant business opportunity for the aggregator.

Figure 12. **Histogram of occurrences of negative prices on the EEX CZ intra-day market**, EUR/MWh



Source: OTE, 2021

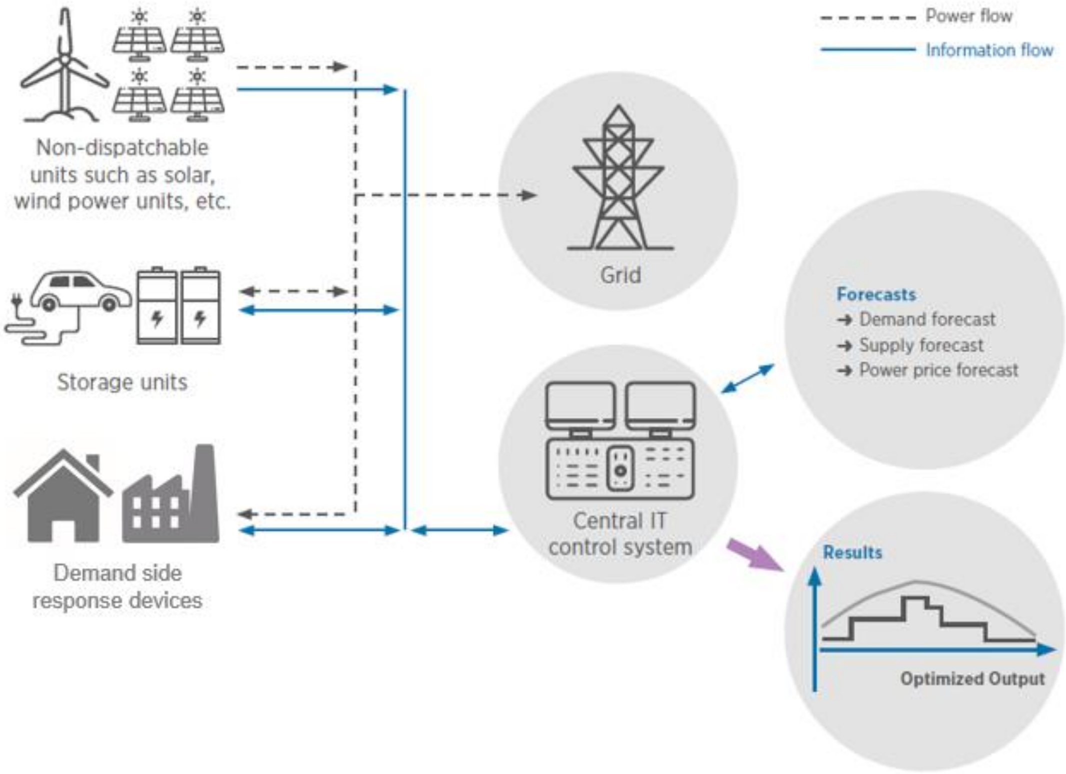
These figures imply that day-ahead data should be sufficient to test how feasible LV DSR aggregation could be for wholesale market.

c. Independent aggregators

With gradual decentralization of the electricity markets, more sub-scale producers will generate power while more consumers will be able to respond to price signals by varying their electricity consumption. An aggregator is an entity that groups together energy supply or demand of these sub-scale players to participate on the wholesale energy or ancillary services markets. Aggregating power producers to participate on the wholesale power market is considered a 'virtual power plant' and is already relative common. Power generation aggregators typically consist in tens of renewable or CHP plants with predictable behaviour, not hundreds or thousands of consumers with quite varying and unstable consumption profiles.

Figure 13 illustrates how an aggregator works for demand side response. DSR aggregators maintain contractual relationship with the owners of storage units (home batteries, electric vehicles) and dispatchable devices. These owners allow aggregators to alter their power consumption within certain limits (e.g., temperature boundaries, minimum battery charge) to adjust their power demand. This potential power demand reduction can be sold to the system operator as positive ancillary service or on the wholesale market as power generation. Revenue streams from these sales then trickle down to the device owners which motivates them to offer their devices to the aggregator. Power flows from non-dispatchable generation remain unchanged. However, data on their current and future power generation helps aggregators to improve power supply forecast and hence optimize energy demand at their flexibility providers, such as creating temperature or battery charge buffer that can be used in expected power supply shortage periods.

Figure 13. **Illustration of aggregation**



Source: IRENA, 2019b. Adjusted by the author

There are two main types of aggregators: Integrated and Independent. While integrated aggregators are responsible for the system imbalance their customers cause in the energy market, i.e., they are the Balance Responsible Party (BRP), the independent aggregators are not. The integrated aggregator concept is relatively straightforward and already present on the Czech market. The flexibility providers under the integrated aggregator are expected to consume certain amount of energy which the integrated aggregator already bought on the market for each hour. If DSR is activated, the overall energy demand of the integrated aggregators is reduced, and the excess energy is sold off. In this case, all commercial and data flows remain in one entity, typically existing energy supplier.

On the other hand, an independent aggregator does not have to procure any energy beforehand. It only maintains flexibility contracts with its customers while energy supply contracts can be held by another entity. In this case, activation of DSR reduces consumption of customers of energy suppliers which may not be involved at all in any flexibility contract. Their energy demand is lower than what they procured and should be liable for this imbalance. However, this imbalance is a result of flexibility command and hence should not be penalized. Defining proper baseline consumption for each impacted energy supplier and its customers and differentiating imbalances between ordered flexibility and failing demand prediction brings a lot more complexity in the data flow and financial compensations (Deloitte, 2018).

Still, there are benefits to introduce independent aggregators to the Czech electricity market despite this increase in complexity. Firstly, instituting independent aggregators is mandated by EU law as a part of its energy transition legislation. Secondly, independent aggregator can prevent inefficient monopoly situation on the market when flexibility providers could only work with their energy supplier as an aggregator. Thirdly, “the independent aggregator is likely to enable more specialised products and services” (Kerscher and Arboleya, 2021) leading to better fit with customer needs. Lastly, more competition reduces prices for the final power customers through lower fees for auxiliary services and increases reward for the individual flexibility providers.

In the Czech Republic, independent aggregators might play more important role due to the recent energy supplier defaults which massively increased electricity bills for hundreds of thousands of Czech consumers. Firstly, there are now fewer outstanding electricity suppliers on the market to become integrated aggregators. Secondly, entrance of any new energy supply is likely to be more complex because of planned increase in regulation. Thirdly and maybe most importantly, many Czechs have lost faith in alternative energy suppliers and hence will likely remain with or switch to large incumbent energy suppliers which typically display less creativity in product offering than new incoming players. On the other hand, flexibility providers might be more reluctant make a flexibility contract with a smaller independent aggregator than with an established energy supplier.

ČEPS has updated its Grid code in June 2021 to allow for participation of smaller players in bidding for the FCAS by reducing the minimum bidding size from 10 and 3 MW to 1 MW (ČEPS, 2021). The update also allowed participation of integrated aggregators in provision of FCAS. First two of such integrated aggregators, innogy Energo and Nano energies, were already certified in 2021 to provide mFRR15 ancillary service (ČEPS, 2021b). These will mostly use generation capacity of subscale (0.5-1.5MW) CHP plants. However, onboarding has already started for high- and medium-voltage commercial and industrial players such as cooling plants, steel plants or cement plants to start providing flexibility via demand side response. The aggregators need to have good business insights for each type of customers they aggregate as their energy needs and hence flexibility potential differ a lot, so the offers and flexibility profiles need to be industry specific (oEnergetice, 2018).

United States and Western and Northern Europe represent the most mature energy markets in DSR aggregation with many relatively advanced players active on the market such as Flexitricity (UK), Restore (EU, US), Next Kraftwerke (Germany), or Open Energi (UK). For now, these aggregators stay away from residential demand aggregation with exception of electric vehicles (oEnergetice, 2018). The markets need to first mature with industrial and commercial players before moving to residentials (Kerscher and Arboleya, 2021). Besides the large size and economies of scale, large industrial and commercial players benefit from existing energy management infrastructure, predictable baseline consumption, and defined data-privacy agreements.

Still, several companies have implemented small-scale residential DSR pilots to prove the technology and learn customer behaviour. Tesla has installed batteries and solar panels to 1,100 homes in South Australia which can be operated as one aggregated system (IRENA, 2019b). Ecogrid 2.0 has successfully demonstrated flexibility aggregation from 800 households with heat pumps and electric heating panels for over 3 years, reacting to grid needs and even controlling for rebound effects (Ecogrid 2.0, 2019).

Lastly, to enable large-scale LV aggregation, market needs a central infrastructure entity and standardization among OEMs to reduce unitary capex for each installation. Given relatively low amount of flexibility each LV device can provide, high unitary capex would become prohibitive as the fees from providing flexibility would struggle to recover the initial investment. To tackle exactly this issue in a concentrated manner, several leading European TSOs have joined forces in Equigy. This blockchain-based crowd balancing platform should allow for nearly “plug-and-play” solutions for participation of LV devices in demand side response offerings (Equigy, 2020). On top, Equigy “… will work in collaboration with OEMs to create the ‘de facto’ European standard for a B2C ancillary services market using distributed energy resources” (Equigy, 2020b), which should further broaden access of devices to the flexibility market.

d. Low-voltage demand side response potential

In thesis, I investigate the following LV technologies for flexibility:

- electric heating (heat pumps, convector heaters, electric heating foils, electric boilers),
- electric water heating with accumulation,
- home batteries,

- electric vehicle chargers,
- fridges / freezers.

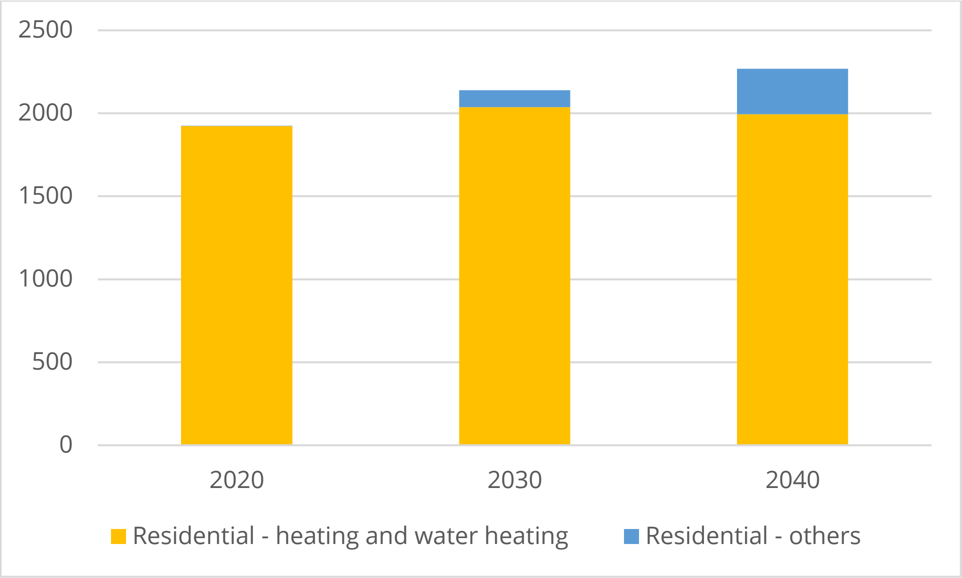
This is not exhaustive list as there are many other technologies with similar potential such as pool heating or air conditioning. This thesis directly excludes from low-voltage flexibility cycle-based home appliances. Washing machine, clothes dryer or dishwashers need to finish specific processes which cannot be interrupted based on immediate instruction by the aggregator. Hence flexibility stemming from turning on and off these cycle-based appliances would be much easily accessed by different predictable tariff structure rather than flexibility aggregation.

To assess the low-voltage flexibility potential, I split the devices into three groups: heating and water heating devices, electromobility, and other low-voltage dispatchable devices. While using heating and water heating devices and electromobility for flexibility is already proven model with aggregators in Western Europe, other LV devices are less mature.

A 2018 NAP SG study presents the key numbers for LV devices flexibility potential (NAP SG, 2018). Estimating flexibility on the consumption side is complex from several perspectives. Firstly, not all technically available device consumption is available for flexibility as energy consumption of these devices exhibit large month-on-month, day-on-day as well hour-on-hour variability. Only certain share of devices will be consuming energy at any point in time. Secondly, dispatchable electrical devices consumption will change based on adoption rate and energy efficiency achievements. For example, replacement of gas and coal boilers by heat pumps will increase available flexibility. On the other hand, investments to house insulation and energy efficient heat pumps will decrease the consumption and hence the available flexibility. Thirdly, only “smart-enabled” devices will be able to participate on the flexibility market. Hence adoption rate of smart meters and smart devices will influence flexibility development. Lastly, different types of required flexibility will match demand side response availability. In general, residential DSR is better suited to provide shorter ancillary services rather than hourly demand reductions.

Figure 14 displays future outlook on realistic potential of flexibility of low-voltage residential appliances. Heating and water heating flexibility significantly surpasses flexibility from other residential appliances. Within heating devices, large growth is expected especially for heat pumps which will gradually replace other heating options. The overall flexibility potential is very large and keeps constant around 2,000 MWs. However, even the authors of these predictions warn that these estimates might suffer from inaccuracies listed above. Still, even one half of this flexibility would nearly cover the positive ancillary services demand of 1,100 MW.

Figure 14. **LV residential positive flexibility potential**, MW



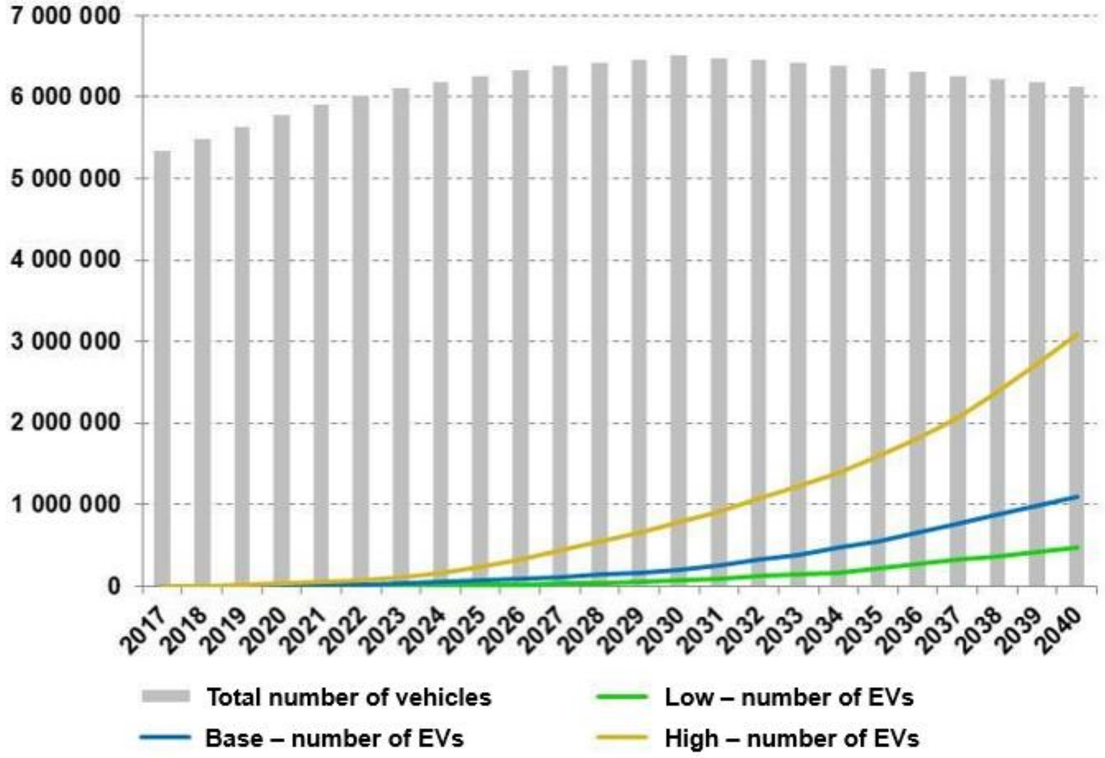
Source: NAP SG, 2018

Within LV electromobility, I focus on personal vehicles. Trucks, electric buses, and other electrified public transport vehicles are likely to be using MV chargers and benefit from tailor-made offering from aggregators. On the other hand, personal vehicles will be mostly charged at local LV residential chargers.

Flexibility for personal vehicles can come from two forms: either delayed charging or vehicle-to-grid (V2G) systems when vehicle battery discharges to the grid. V2G brings a lot of more options to the design of a flexibility offering but also brings a lot of complexity – effect on battery lifetime through multiple charge-discharge commands, ownership of the flexibility between the vehicle owner and the charging station owner, aggregation of the same battery at multiple locations with different energy suppliers and even at different distribution networks. To further simplify the potential description, I focus on the delayed charging which is an analogy to delayed consumption of heat pumps or water heating.

NAP SG has commissioned a study on future development of electromobility (NAP SG, 2018b). This study developed quite detailed predictions on penetration of electromobility and its impact on the grid. Figure 15 shows three possible scenarios for development of electromobility in the Czech Republic – low, base, and high. In 2030, the share of electric vehicles ranges from 1% to 13% based on scenario. Base case assumes 2%. In 2040, the share of electric vehicles ranges from 7% to 49% based on scenario. Base case assumes 18%. This 18% includes over 1 million electric vehicles connected to the Czech grid.

Figure 15. **Prediction of number of electric vehicles in the Czech Republic**, units

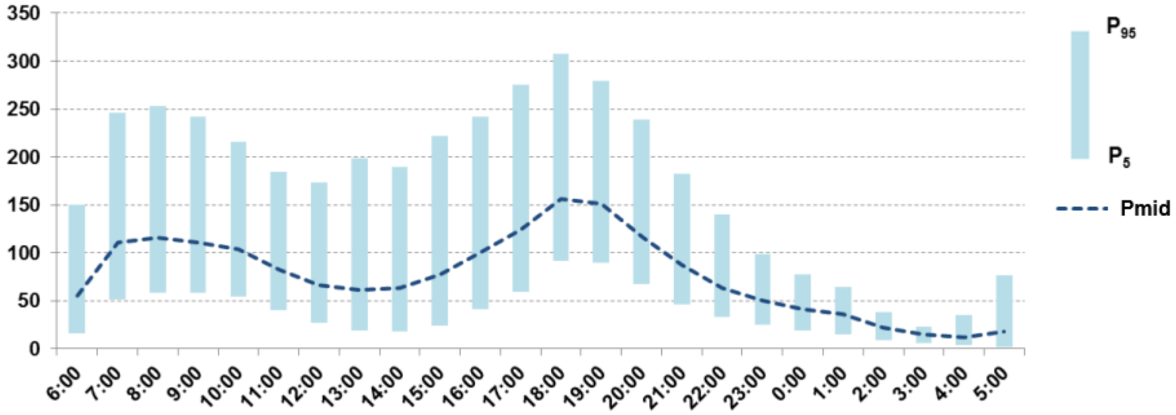


Source: NAP SG, 2018 (b)

This growing number of personal EVs will have a big impact on the energy consumption. The predicted daily energy consumption chart is presented in Figure 16 and Figure 17 for 2030 and 2040, respectively. The unaltered daily consumption pattern unfortunately follows the traditional residential consumption pattern of smaller morning peak and higher evening peak with large consumption drops during the night. This pattern would further increase the pressure on the grid during the peaks and hence some peak shaving technique will need to be employed to reduce its effect.

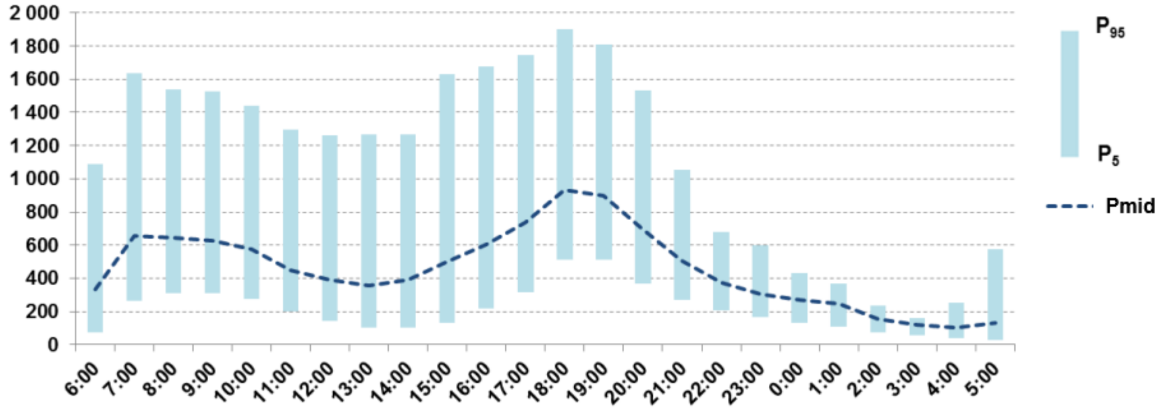
In 2030, the peak consumption is expected to reach 150 MW with daily average around 80 MW. Also, part of this charging will take place at MV charging stations, either at dedicated charging stands or at commercial establishments such as malls or office buildings. This means there is relatively small potential for LV flexibility at personal vehicles in 2030. However, given the quickly growing presence of EVs, 2040 flexibility potential seems much larger. The peak consumption is expected to reach over 900 MW with daily average around 500 MW. Even with deductions for MV charging points, this can already represent a significant flexibility potential for ancillary services market, which currently demands around 1,100 MW of positive ancillary services.

Figure 16. **Daily EV charge energy consumption for personal vehicles (Base case, 2030)**, MW



Source: NAP SG, 2018 (b)

Figure 17. **Daily EV charge energy consumption for personal vehicles (Base case, 2040)**, MW



Source: NAP SG, 2018 (b)

e. Access to flexibility between DSOs and aggregators

Part of the flexibility from the previous section is already captured by ripple control (HDO) which is nearly universally present across the Czech grid with around 1.2 million receivers. In the current setup, ripple control is managed by the DSOs which use it mainly for peak shaving to reduce grid losses, limit investments to strengthen the grid, and balance the grid. It is estimated that up to 2,500 MW worth of devices can be turned on and off based on tariff schemes using HDO. In practice, around 500 MW are switched on and off in the grid in a typical consumption period (NAP SG, 2016). HDO-enabled devices consume around 4.3 TWh annually, i.e., 7 % of annual electricity consumption of the Czech Republic.

The HDO-enabled devices are listed by the Czech regulator ERÚ, linked to specific tariff classes, and include convector heaters, heat pumps, hear accumulators, and water boilers. Owning one of these devices allows energy customers to receive two-tier tariff scheme, which is roughly 30% cheaper than the single-tier tariff scheme but requires turning off the HDO devices during the peak hours.

Despite its historic success, HDO suffers from several issues which will be difficult to rectify (Zandl, 2016). Firstly, HDO entails unsecure commands running in an open network, hence relatively easy to tamper with. Turning off ripple control at a time of peak demand could potentially lead to grid overloading and risks to the grid stability. Secondly, HDO can provide for only limited number of commands given its frequency-based technology, which reduces its applicability to wider variety of tariff schemes, geographies, or technologies. Thirdly, HDO does not allow for a third-party access. It is owned and operated by monopoly DSOs which reduces its usability for creative commercial offers that provide benefits to end users for specific changes in their electricity demand. Fourthly, HDO does not track any real-time data and assumes consumption changes based on grid averages. Lastly, given its dedicated circuit dependency, HDO does not cover many other LV dispatchable devices such as air conditioning, pool heating, or batteries.

HDO can deliver large chunk of electric heating flexibility. However, customers can currently only choose whether to opt for the two-tier tariff schemes or not. Participating in aggregation of their smart-enabled devices can provide much more tailor-made offering for each customer, significantly increasing their benefits from active energy management.

NAP SG currently predicts co-existence of HDO and smart grid flexibility devices even during the 2030-2040 period, mainly to solve emergency power shortage situations (NAP SG, 2015). There are multiple models being considered on how a DSO and an aggregator could deal with the same flexibility providers. In the first model, a DSO excludes certain devices, most likely those currently in the ripple control regime, from aggregator's access and uses them exclusively for its load balancing. In the second model, a DSO yields its access to all the devices to an aggregator. In the third, combined model, a DSO and an aggregator coordinate and negotiate each flexibility activation.

Each model has its drawbacks which limit its use in the short term. First model does not support creation of new flexibility offerings as most flexible devices will be managed by a DSO. The second model creates too many risks and extra costs to a DSO. The third model presents too much complexity and slowness in response to prices and loads. Hence a combination model, fourth model, is likely to emerge, where an aggregator can have direct access to all the devices while a DSO reserves the "last resort" option to tun off device in case of emergency (Eurelectric, 2015). This enables development of new flexibility offerings, limits risks to a DSO, and enables fast reaction times. Details of this model, including compensation between a DSO and an aggregator or estimating the frequency of the last resort events, are beyond scope of this thesis.

Overall, flexibility can be activated as a response to a command or to a price threshold. Price responses are in general preferred due to their market-based nature. Expanding the price response to retail customer by DSO-mandated time-varying dynamic tariffs is an additional solution on how to tap into LV flexibility without aggregators which is expected to be implemented by most of the European DSOs (Kerscher and Arboleya, 2021). This naturally creates risk for any aggregator – aggressive dynamic tariffs for critical peak pricing can significantly reduce consumption of the flexibility providers as each demand side response cannibalize on mostly the same consumption (Eurelectric, 2015). Aggregator might then be unable to fulfil its commercial obligations as there might not be any more demand to be reduced.

Dynamic tariffs are expected to be fully integrated in the Czech energy grid by 2035 (NAP SG, 2015). Price signals will allow for cost-efficient load management while keeping options open for customers. Pricing of these tariffs will give direct comparison to any potential investment to strengthen the grid and hence reduce the need for big difference among rates in the dynamic tariffs. On the other hand, DSO will use dynamic tariffs to optimize its own network, which might be sub-optimal from the perspective of the entire power grid. Aggregator responding to TSO's ancillary services might be then preferred. In any case, there is a need for command flexibility to guarantee change in demand, especially for ancillary services. Comparison of dynamic tariffs and DSR aggregation and their mutual interaction is again beyond scope of this thesis. For further analysis, I focus on the total consumption of the flexibility providers which should not influence the total flexibility offered.

Even though future relationship between HDO and smart device flexibility offerings is yet to be defined, allowing for more options to customers will certainly unlock more of the predicted 2 GW flexibility potential at residential customers. Economically motivated customers should start switching from HDO managed flexibility to aggregator-managed flexibility to actively benefit from their existing power consumption.

f. Exclusions and extensions

For successful entry of independent aggregators in the Czech electricity market, there are several other barriers that need to be overcome which this thesis does not aspire to cover. Still, these are briefly summarized below.

Regulatory environment. The concept of the independent aggregator has not yet been transposed to the Czech energy law. There are several key considerations that legislators need to decide, namely on the relationship of an independent aggregator to energy providers. The study "Role agregátora v české energetice" (Deloitte, 2018) describes well the potential organizational setups and its implications. The new "Energy law" is currently being drafted and the current draft includes many of the new energy concepts currently missing in the law, such as prosumers, providers of energy accumulation, and also independent aggregators (MPO, 2021). However, the law will not come into effect before 2023.

Baseline calculation. To evaluate performance of the aggregator and its flexibility providers, clear baseline demand needs to be established and agreed by all parties. Selection of the appropriate methods to set up correct energy baseline for different flexibility technologies as well as mixed technology flexibility offerings will be essential. This includes factors influencing accuracy and variance of the baseline such as load, time of the day, or climatic conditions.

Rebound effect. Rebound effect, an increase in demand after the end of forced demand curtailment, is likely to occur with most of demand side responses (Eurelectric, 2015). Methods to smooth out this rebound need to be defined. This includes evaluation of the rebound effect for different technologies in terms of timing, ramp-up curve, and overall size of the demand spike. Secondly, rebound effect causes an additional imbalance for energy suppliers as they might need more power than originally expected, which will require clear accounting and responsibility rules.

III. Flexibility sizing for individual devices

a. Distribution tariffs, relevant appliances, and synthetic load profiles

To evaluate economic feasibility of providing flexibility, I need to firstly define amount of flexibility available and usable in specific time periods. This flexibility will differ by type of electric device used by the consumer. Czech electricity regulation defines customer groups by types of high-consumption electric appliances installed. Customers with such appliances, typically for heating and water heating, benefit from lower prices for distribution fees as their consumption is associated with more stable consumption and hence lower distribution grid operations costs. Overview of the distribution tariffs for commercial and residential customers is presented in Table 2 and Table 3.

Table 2. **Distribution tariffs for LV residential customers in 2021**[1]

	Description	Number of customers	Total consumption	Consumption per customer
		-	MWh	MWh/custom.
D01d	Small consumption, no special appliance	715,524	490,268	0.7
D02d	Average consumption, no special appliance	2,797,539	4,846,602	1.7
D25d	Electric water heaters with accumulation	1,047,351	4,160,522	4.0
D26d	Accumulation heaters	64,230	480,054	7.5
D27d	Electric vehicles	521	1,999	3.8
D35d	Hybrid heating (no longer active)	11,559	86,201	7.5
D45d	Convector heaters (no longer active)	425,790	3,897,654	9.2
D56d	Heat pumps (no longer active)	56,291	738,672	13.1
D57d	Electrical heating: heat pumps, convector heaters	195,428	1,493,665	7.6
D61d	Weekend consumption	6,987	8,339	1.2
Total		**5,321,220**	**16,203,976**	

Source: ERU, 2021

Table 3. **Distribution tariffs for LV commercial customers in 2021**

	Description	Number of customers	Total consumption	Consumption per customer
		-	MWh	MWh/custom.
C01d	Small consumption, no special appliance	242,012	240,962	1.0
C02d	Average consumption, no special appliance	261,481	1,592,609	6.1
C03d	High consumption, no special appliance	17,607	922,784	52.4
C25d	Electric water heaters with accumulation	112,786	1,809,752	16.0
C26d	Accumulation heaters	7,565	644,558	85.2
C27d	Electric vehicles	85	611	7.2
C35d	Hybrid heating (no longer active)	1,465	93,926	64.1
C45d	Convector heaters (no longer active)	52,858	1,660,056	31.4
C46d	Convector heaters or hybrid heating	1,762	21,477	12.2
C55d	Heat pumps (no longer active)	402	15,235	37.9
C56d	Heat pumps	3,143	77,626	24.7
C60d	Irregular and small consumption	8,869	-	-
C62d	Public lighting	36,596	610,072	16.7
Total		**746,631**	**7,689,668**	

Source: ERU, 2021

I highlighted in grey the distribution tariffs I further analysed for flexibility potential in the tables. These were selected based on availability for flexibility, overall group consumption, and consumption per customer. The selection of analysed devices is as follows:

- Electric water heaters: C25d, D25d
- Convector heaters: D45d, C45d

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[1] Includes several "no longer active" distribution tariffs. Many customers historically received these tariffs, but no new customers can now obtain it.

- Heat pumps: D56d, D57d[2]

As a separate exercise disregarding the distribution tariffs, I looked into potential flexibility offered by several other devices. The results are in the last subsection of this section.

To obtain statistically relevant outcomes, I relied on the synthetic load profiles (TDD) reported by OTE (2021). This data represents hourly consumption pattern throughout the year for different customer groups. TDDs are inaccurate for individual customer, but statistically accurate for groups of customers (Eurelectric, 2015), which is essential for any aggregator. In order to define hourly available flexibility, TDDs can be used due its statistic representativeness on large sample, while requiring further processing given individual customer consumption patterns (Eurelectric, 2015). ERU specifically links reported TDDs to distribution tariffs. This matching is presented in Table 4, with select tariffs highlighted in bold.

Table 4. **Pairing of distribution tariffs to TDDs**

TTD class	Distribution tariffs
TDD 1	C01d, C02d, C03d
TDD 2	**C25d**, C26d, C35d
TDD 3	**C45d**, C55d, C56d
TDD 4	D01d, D02d, D61d
TDD 5	**D25d**, D26d
TDD 6	D35d
TDD 7	**D45d**, D55d, **D56d**[3]
TDD 8	C62d

Source: ERU, 2005

b. Heating and water heating – Methodology of flexibility sizing

I present below the approach to estimate the flexibility for electrical heating of residential customers. Firstly, I estimate the typical hourly consumption of the households by combining the hourly TDDs with the average annual consumption per household for the selected distribution tariffs as well as for D02d for comparison. The daily data by day are presented in Figure 18.

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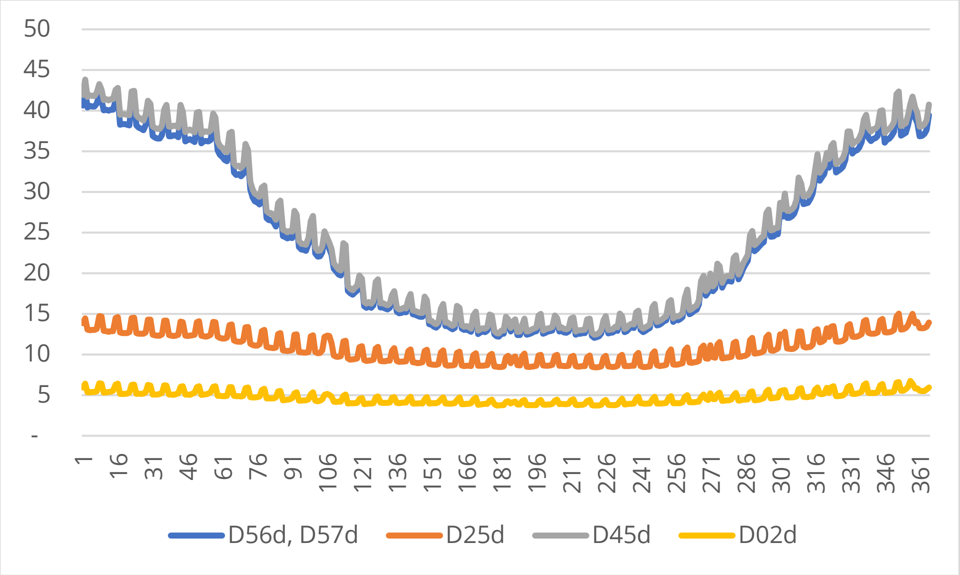
[2] Even though D57d includes other devices than just heat pumps, over 50% of the customer use heat pumps. This was deduced from the Czech Ministry of Industry and Trade statistics on total heat pumps installed and annual additions (MPO, 2019).

[3] D56d is an old tariff for heat pumps. ERU does not define TDD for the new heat pump tariff D57d. For this analysis, I assume D57d shares the TDD with D56d.

Figure 18. **Average daily consumption by distribution tariff**, kWh



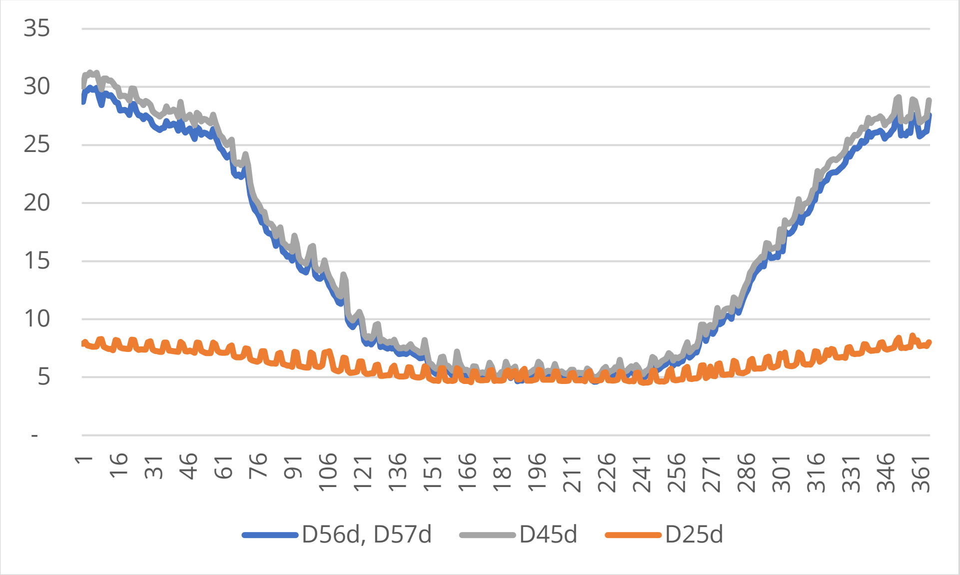
As expected, the data presents two types of trends. Firstly, households with heating devices (D45d, D56d, D57d) have significantly higher consumption during winter months. Winter month power consumption tends to be up to 7 times higher than consumption of households without any electric or water heating and up to 3 times higher than consumption of households with only electric water heating. This difference is significantly reduced to roughly 5 kWh per day in the summer where no heating is needed. This difference is caused by electrical heating being used more commonly in houses rather than apartments which are typically heated by other means. Houses have in the summer higher consumption, be it from potentially other flexibility sources (air conditioning, more energy for water heating due to higher number of household residents) and non-flexible devices given bigger surface or more household members.

Secondly, there is an obvious weekday-weekend differentiation. Household members spend more time at home during weekend and hence their consumption is growing by around 8% on average.

These two trends imply two aspects of the flexibility potential analysis. Firstly, I analyse flexibility of cold and warm months separately as these will change quite dramatically. Secondly, I analyse flexibility of weekdays and weekends separately.

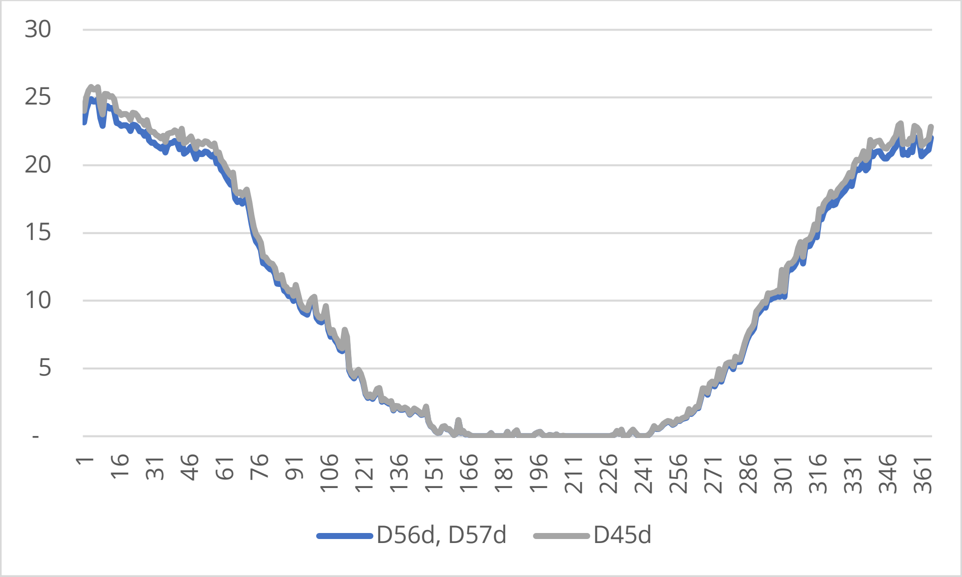
To estimate flexibility, I subtract from the average consumption of the electrical heating and electrical water heating households the average consumption of a typical household without any such appliances (D02d). To account for higher consumption due to higher prevalence of electrical heating in houses relative to apartments, the consumption of the typical D02d household is normalized by a factor of 2 in case of electrical heating households. This factor puts the summer consumption of the electric heating households in line with the summer consumption of the electric water heating households. The resulting consumption pattern then presents the consumption of only electric heating and electric water heating devices, as illustrated in Figure 19.

Figure 19. **Average daily consumption of electrical heating and water heating devices by distribution tariff**, kWh



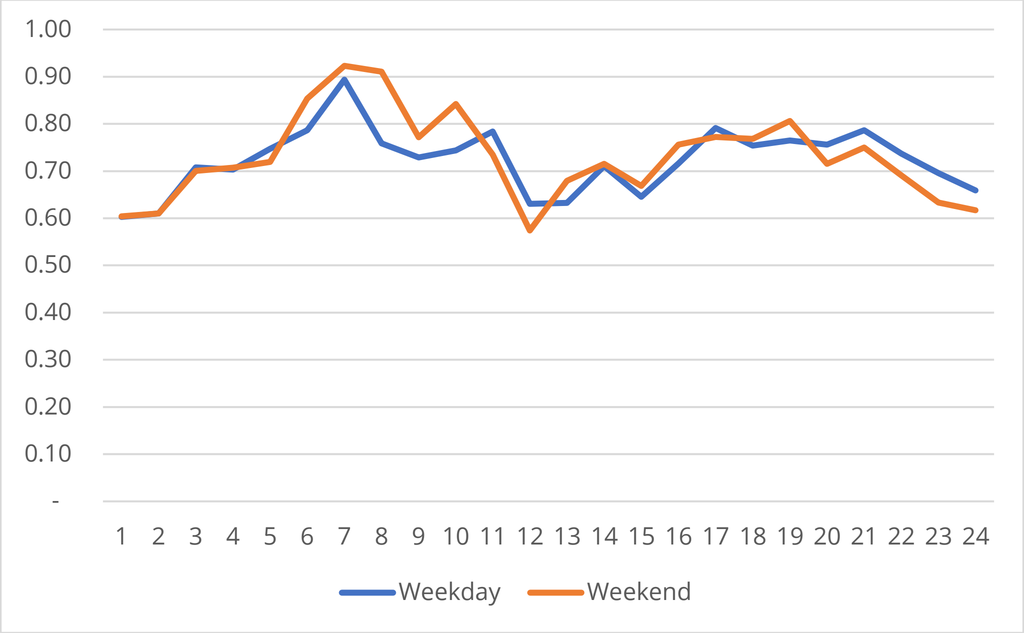
Finally, as water heating and space heating for heat pumps or convectors are independent systems, I have subtracted the consumption for water heating from the space heating. The water heating consumption is defined as average summer consumption (June, July, August) where typically no electricity is consumed for heating. Overall, this assumes that households with electrical space heating also use electrical power to heat water. This assumption should hold true in vast majority of households since if other primary energy source if used for water heating (natural gas, biomass, coal), it would be also used for space heating. As a result, Figure 20 illustrates consumption of only the space heating.

Figure 20. **Average daily consumption of electrical space heating devices by distribution tariff**, kWh



Consequently, I apply similar logic to hourly data. For electric heating, it makes sense only to analyse the data for the heating season (October to March). Also, as discussed before, I calculate the data separately for weekdays and weekdays as well as for different tariffs. The results for heat pumps are presented in Figure 21. Very similar outcome is derived for convector heaters since they are based on the same synthetic load profiles (TDDs).

Figure 21. **Average hourly consumption of electrical space heating devices for distribution tariffs D56d and D57d (heat pumps) during the heating season**, kWh



These charts define hourly consumption of electrical heating that can be moved around and hence present flexibility potential. As discussed before, this potential is partly limited by HDO which already causes some of the visible consumption dips in the charts.

Average daily consumption of a heat pump for space heating during the winter season is around 17 kWh. This is the consumption that can be moved around and hence some of it offered as a flexibility on either the ancillary or the wholesale markets.

c. Heating and water heating – Summary of flexibility potential

Similar approach was taken for convector heating and water heating for residential customers and convector heating and water heating for commercial customers. Normalization factor used for space heating for commercial customers was 2.5 instead of 2, which brings the summer consumption of space heating customers on par with the summer consumption of the water heating customers. Table 5 presents the summary for the 5 customer groups representing the selected 6 distribution tariffs.

Table 5. **Summary of flexibility potential by customer group – daily**

	Device	**Dx tariff**	**Season when flexibility calculated**	**Share of flexible consumption**	**Average weekday consumption**
				%	*kWh/day*
Residential	Heat pumps (space heating only)	D56d, D57d	October-March	40%	17.35
	Convector heaters (space heating only)	D45d	October-March	40%	17.98
	Water heaters	D25d	Full year	56%	5.91
Commercial	Convector heaters (space heating only)	C45d	October-March	24%	39.17
	Water heaters	C25d	Full year	62%	28.61

For residential customers, space heating could on average provide 17-18 kWh per day of flexibility. These customers typical also use electricity for water heating which adds additional 6 kWh daily of flexibility device consumption, not accounted for in Table 5. Commercial customers have on average roughly twice the flexibility potential in heating but 4-5 times higher potential in water heating. This might indicate to high prevalence of customers with high hot water consumption (restaurants, hotels).

Figure 22, Figure 23, Figure 24, and Figure 25 display the average hourly consumptions for the remaining 4 customer groups. The daily space heating consumption profiles of heat pumps and convector heaters do not differ between each other because they are based on the same synthetic load profile. On the other hand, commercial space heating differs by having a prominent drop during weekends where some of the commercial establishments such as shops are not open.

For residential water heating, the hourly consumption curve displays steeper curves with two clear spikes which is driven by having only 8 hours of low-rate tariff for water heating instead of 20 hours for space heating. Also, the morning weekend curve for water heating is clearly shifted 2 hours backward as people delay their morning routines relative to weekdays, which influences HDO timing.

Figure 22. **Average hourly consumption of electrical space heating devices for distribution tariff D45d (convectors) during the heating season**, kWh

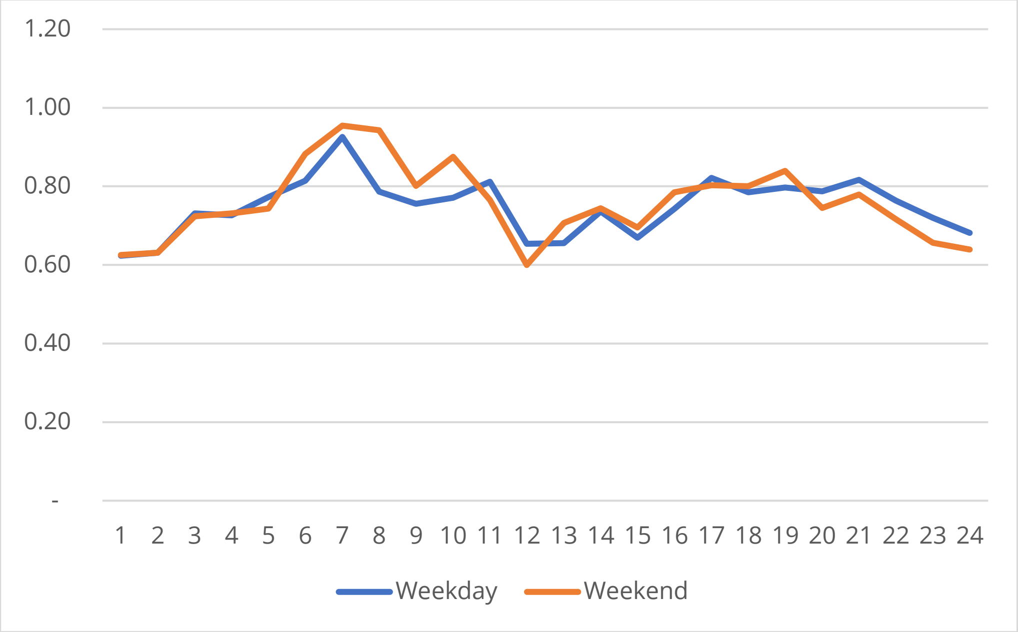


Figure 23. **Average hourly consumption of water heating devices for distribution tariff D25d (water heaters) during the full year**, kWh

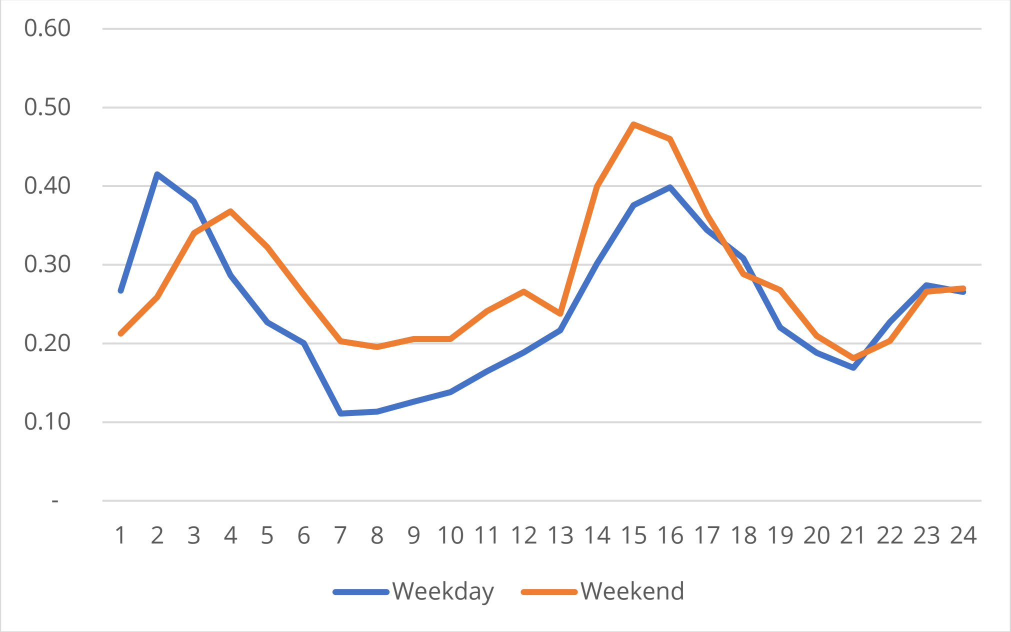


Figure 24. **Average hourly consumption of electrical space heating devices for distribution tariff C45d (convectors) during the heating season**, kWh

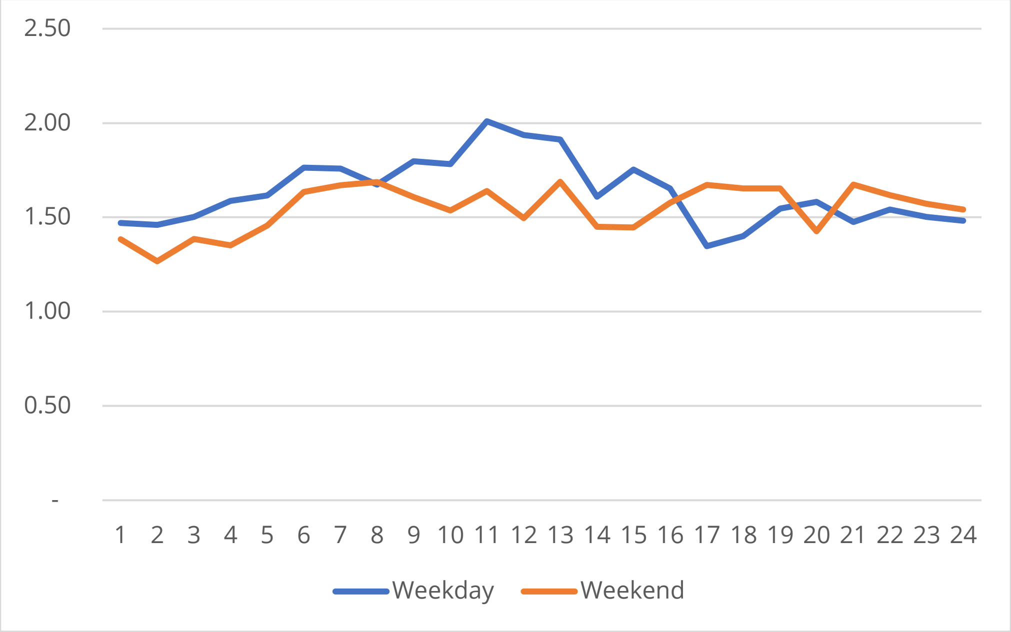
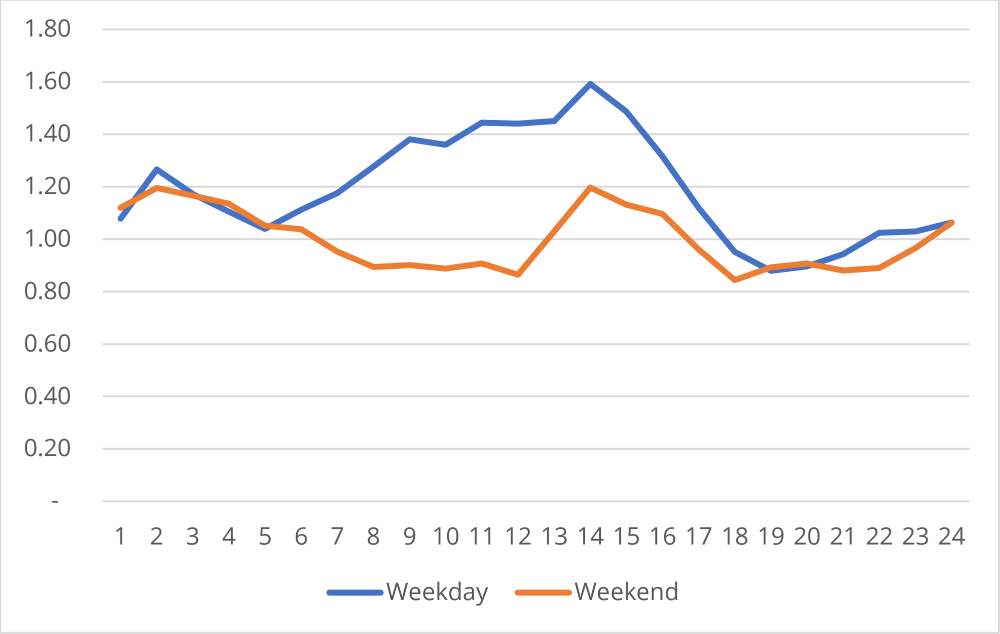


Figure 25. **Average hourly consumption of water heating devices for distribution tariff C25d (water heaters) during the full year**, kWh



All these estimates are naturally only averages. There will be customers with twice the potential and customers with half the potential. Customers with higher potential will likely be those more interested in participating and will be of higher interest to any aggregator.

This bottom-up approach also confirms sizeable flexibility potential for these customer groups for the entire grid. Table 6 presents the average load of the flexibility devices in the grid. Residential water heaters and convector heaters present the highest potential. Overall, LV residential devices also have 3.2 times higher flexibility potential than LV commercial devices. Together, these 5 customers groups are estimated to have 1.2 GW flexibility potential during the heating season and 0.6 GW flexibility potential outside of the heating season. This figure naturally varies based on specific hour in the day and the associated consumption patterns. However, it roughly compares with the 1.9GW / 500 MW of flexibility predicted by NAP SG (2018) for 2020 given the caveats listed in Section II.

Table 6. **Summary of flexibility potential by customer group – hourly**

	Device	**Dx tariff**	**Average weekday daily load per hour**	**Number of customers**	**Total average weekday daily load per hour**
			kW/device	#	MW
Residential	Heat pumps (space heating only)	D56d, D57d	0.72	251,719	182
	Convector heaters (space heating only)	D45d	0.75	425,790	319
	Water heaters	D25d	0.25	1,724,860[4]	424
Commercial	Convector heaters (space heating only)	C45d	1.63	52,858	86
	Water heaters	C25d	1.19	165,644	198

d. Flexibility potential of other appliances

There are several other appliances which might be usable for flexibility. Yet, these are not grouped by any distribution tariff with synthetic load profiles.[5] I need to estimate flexibility potential based on example devices, not on aggregate data. Due to this lower representativeness, I dedicate less space in this thesis to such devices. Below, I present the flexibility sizing logic for home batteries, EV chargers, and fridges/freezers. Other devices such as pool heating or air conditioning are not discussed. These other devices might be interesting in the future from the perspective of seasonality. While switching off heating can be utilized for flexibility only during the heating season, switching off air conditioning can be utilized for flexibility exactly outside the heating season, creating potentially a complementary offering.

Home batteries

Batteries have been long considered the ultimate solution to stabilizing the electricity grid (IRENA, 2017). However, their mass deployment in the grid is prevented by high capital costs. Despite several large pilots, no utility-scale battery system has been deployed in the Czech grid. At the same time, Czech households are commonly installing these batteries, mostly to maximize the share of power consumed from locally installed PV panels. During the winter months, these

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[4] Includes customers from space heating as well.

[5] Electric vehicles have their own dedicate distribution tariff D27d but given its currently very low uptake, there are no relevant granular data for TDD analysis.

batteries tend to be underutilized due to low solar radiation. This capacity could be aggregated to provide a range of services to the grid, mostly in load shifting, black start, voltage support, or frequency regulation (Fitzgerald et al., 2015).

To calculate the flexibility potential, I chose the Tesla Powerwall II as an example battery on the market. It is a 13.5kWh / 5kW system commonly deployed in houses. I further assume that in non-heating season (April-September), battery is fully dedicated to increasing PV self-consumption.[6] During the heating season (October-March), I estimated that only 25% of the battery is used to increase PV self-consumption, the rest can be used for ancillary services. Assuming 95% charge of the remaining 75% available for ancillary services, the home battery owner could offer a 9.6 kWh / 5 kW system to the grid during the 6 months of heating season.

It needs to be noted that this is highly simplified logic to estimate rough potential. Rebound effect requiring charge before further discharge needs to be considered. Batteries get damaged by frequent charge and discharge cycles as lifetimes typically depend not on years in service but on the number of charge/discharge cycles.

Electric vehicle chargers

When V2G systems become available, electric vehicles will become in essence mobile battery systems providing flexibility similarly to the home battery systems, even though typically with much larger capacity and charge power. V2G still requires solving several design questions, mainly around accounting for the service provided at different locations served by different energy suppliers and even different DSOs. In the meantime, I focus on flexibility offered by the electric charger by postponing charge of an EV connected at home. At that time, EV can be treated for flexibility similarly to heating or water heating.

I need to estimate the average daily consumption of the EV charger. Firstly, I assume an average EV drives 15,000 km per year, comparable to an average Czech car (auto.cz, 2013). This means daily driving of 41 km. If I choose Tesla model 3 as the example device, I use consumption of 0.151 kWh/km. This implies daily charge of 6.2 kWh. Spreading that equally over an average 12-hour period when parked at home and subtracting 25% for out-of-home charging (work, weekends), I arrive at an average charge of 0.39 kW per hour over the 12-hour period.

In practice, time-of-use or ripple control tariffs will be introduced to shift EV load to specific hours in the day. This will lead to higher power demand over shorter period of time, but not changing the overall daily flexible load.

Fridges / freezers

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[6] Besides profitability of self-consumption, at least 70% utilization of own PV production is required to qualify for a capital cost subsidy.

The idea of using fridges or freezer aggregated on the low voltage has been a contentious one. Almenta et al (2015) propose a model for fridge-freezer aggregation in Ireland. However, the study concludes that “current ancillary service payments confirms that these are insufficient to ensure widespread uptake by the small consumer.” Nevertheless, I examine the potential in the Czech market.

Firstly, I estimate annual fridge-freezer consumption. Based on energy class of the device, the consumption varies between 150 and 300 kWh per year. Newer devices tend to be more energy efficient. At the same time, to participate in the load aggregation, customer will need to have a new, smart-enabled device. Hence, I assume annual consumption of 200 kWh per year. If we assume continuous operations, quite likely scenario for a fridge, this means an average hourly consumption at the level of 0.02 kW. This is 10 times lower than water heater at residential customers, which is the lowest unitary consumption among the heating and water heating devices. With such a low consumption, the unitary economics of building a platform and adding new customers with fridges or freezers is unlikely to work.

The overall flexibility potential of fridges is also not striking. Fridges are one of the most common devices among LV customers. For simplicity, I assume every household and LV commercial customer has one. This would mean 6 million fridges operated on LV in the Czech Republic. This implies around 140 MW of overall flexibility at any point in time. Even though it is not negligible, the investments needed to connect even a fraction of the 6 million distribution points are likely to prevent an uptake in fridge-freezer aggregation. I do not further analyse fridges-freezer in this thesis.

IV. Methodology of the business case

I present a simplified approach to constructing the business case for an individual flexibility provider. The ambition is not to arrive at a specific number but to obtain an order of magnitude estimate of the fees available to the LV flexibility providers to assess their potential interest.

There has been already proposed multiple optimization models for aggregators to maximize revenues and minimize cost by choosing the right bidding strategy in the energy or ancillary services markets and flexibility dispatching portfolio and sequence (Correa-Florez et al., 2020). The best model was shown to outperform deterministic case by up to 16%. Even though such improvement would significantly alter profitability of an aggregator, it will not change the order of magnitude fees available to the LV flexibility providers. Hence optimization is not considered and instead I look into the average values of flexibility potential and fees available.

Aggregators offering customers’ demand flexibility on the energy market can realistically collect revenues from two sources: ancillary services provided to the

TSO and trading negative consumption for peak periods on the wholesale day-ahead or intra-day market. The main cost buckets discussed include platform costs, unitary capex and unitary opex.

a. Revenues sources – ancillary services

The hourly and daily flexibility was defined in the previous section. The average prices for ancillary services were discussed in Section II. Ancillary services most likely provided by DSR aggregators will be aFRR and mFRR5. Fees are collected both for MW reservation for ancillary services as well as for MWh activation in the form of balancing energy.

OTE (2021) publishes annual report on balancing energy with hourly figures. During 2020, ancillary services were activated only in 3% of the time the services were reserved. This supports an important conclusion for the DSR aggregation: Ancillary services delivered by large spinning reserves are expensive to maintain but profitable to activate. By participating in the ancillary services, part of the plant output cannot be utilized to generate profit. Once activated, the plant generates additional revenues above its marginal costs and hence often desires high level of activation. On the other hand, ancillary services delivered by DSR are very cheap to reserve but very expensive to activate. Reserving DSR means maintaining consumption at status quo. But when activated, reducing customers' power demand is very costly as it limits people preferred consumption.

This implies the overall strategy of an aggregator bidding the LV DSR. It should book its flexibility providers on multiple hours per day, because for every hour activated, i.e., consumption curtailed, one can reserve over 35 hours of ancillary services. The true value for the flexibility providers will come from ancillary services reservation, not from balancing energy activation.

Finally, I propose scenarios on how the flexibility might be offered on the market. These scenarios are artificial but represent a potential offer an aggregator might give to the flexibility provider. Below are proposed two scenarios:

- *4+4 hours.* Reserving 8 peak hours in every day per month, typically 4 hours in the morning and 4 hours in the evening. This implies 6.6 hour per month of curtailed consumption but typically at higher rates.
- *12 odd/even hours.* Reserving 1 hour and then a break for 1 hour in every day per month, overall reserving 12 hours per day reserved. This implies 9.9 hour per month of curtailed consumption at average rates.

The sizing of the fees is then relatively straightforward. I calculated average hourly flexibility for the selected device and scenario (4+4 hours or 12 hours). This indicated how many devices need to be pooled together to create a 1 MW block able to participate in any electricity market. Based on the average ancillary services prices in the bidding period (heating season, full year), I calculated the fees collected by the 1 MW pool for ancillary services per month. On top, further fees are collected for activation but these are below 10% of the total revenues. Lastly, I divide the pool revenues by number of devices in the pool to arrive at the fees per device per month. The results are presented in Table 7.

Table 7. **Summary of the monthly FCAS fees for heating / water heating**, CZK

	Device	**aFRR+**		**mFRR5**	
		4+4 hours	12 hours	4+4 hours	12 hours
Residential	Heat pumps (space heating only)	300	412	153	209
	Convector heaters (space heating only)	312	427	158	217
	Water heaters	112	121	62	67
Commercial	Convector heaters (space heating only)	673	914	342	464
	Water heaters	427	540	234	296

The fees vary based on the flexibility offered. Higher values are for aFRR+, higher-quality ancillary service, more flexibility offered (12 hours scenario) as well as bigger devices (heating, commercial establishments). Overall, the average fees for residential heating vary between 150-430 CZK per month and for commercial from 230 to 910 CZK per month. As noted before, these are only average fees.

The actual fees will be proportionately linked to the overall consumption and customers with higher consumption are likely to be those initially approached by aggregators. A well-insulated household with a heat pump could readily offer 4 hours of no heating as the actual temperate will barely. However, this implies low overall heating consumption, low unitary flexibility potential, and hence low fees to the household for providing flexibility.

Estimated fees for home batteries and EV chargers follow the same logic. Battery could be available 10 hours a day, which allows for charge / discharge cycles after activation, and only during the heating season. EV chargers will be available 12 hours a day during the entire year. The results are presented in Table 8.

Table 8. **Summary of the monthly FCAS fees for other devices**, CZK

Device	**aFRR+**	**mFRR5**
Home batteries (10 hours a day)	2,369	1,204
EV chargers (12 hours a day)	184	101

Home batteries can, unsurprisingly, receive much higher fees than other devices. They can provide much higher power output that can help to stabilize the grid. On the other hand, batteries have additional opex costs linked to charging and higher capital replacement costs due to limited charge/discharge cycles of a battery. Fees available to the EV chargers are relatively small as the overall flexible load is not that large either. This might not matter that much as delaying charging of EV vehicles during the night should have very minor impact on consumer comfort.

There are several caveats to note in these results. Firstly, I use historic pricing of FCAS. These prices are likely to change with market coupling of FCAS on the European level starting in April 2022. Unfortunately, it is very hard to predict future development of FCAS prices. Market coupling should lead to higher efficiency and hence lower prices. The overall energy market turmoil, electricity price spikes and growing penetration of renewables should lead to higher FCAS prices. In this analysis I am using the historic prices – any change in ancillary prices will proportionately increase the fees as ancillary services form over 90% of the renumeration.

Secondly, the dispatch of ancillary services is also changing from April 2022 (oEnergetice.cz, 2022). FCAS are currently dispatched relatively equally across the available providers (pro rata principle) and are driven primarily by reliability and stability parameters or experience of the grid operators. The new dispatch will be driven by offered prices for activation, i.e., merit order dispatch. This should allow DSR aggregators more creative bidding strategy, such as becoming the last resort FCAS with low price for reservation and high price for activation. This also implies that changes in pricing of balancing energy. Its price will no longer be defined by ERÚ but by the most expensive activated ancillary service, de facto market clearing price for balancing energy. Future pricing of balancing energy is also unclear, but since it only represents below 10% of the fees, it will not alter the outcome of the business case.

Thirdly, long-term contract bidding for FACS requires fixed amount of guaranteed flexibility. A participant bids certain amount of flexibility for the full week, not changing the hourly flexibility bid as per the consumption pattern of DSR. To ensure aggregator reaps the entire offered potential from each flexibility providers, it may apply several strategies. Aggregator may bid the excess flexibility on the short-term markets. It can create a flexibility providers portfolio of different devices or flexibility products to achieve stable available flexibility. It can also use some back up flexibility devices such as batteries to create a merged product that reaps full benefit of the offered DSR flexibility. These strategies would also help to balance the load within the portfolio to prevent prolonged activations which would increase customer discomfort and prevent customers from catching up with consumption.

Fourthly, despite lower prices, long-term FCAS contracts might be better than short-term contracts if higher prices of short-term contacts result in higher rate of activation. At the time of stress on the grid the price goes up and probability of activation should also increase. However, customers are likely to prefer slightly smaller renumeration if it leads to reduction in activation frequency. On top, long-term contracts remove part of the aggregator risks. If short-term FCAS contracts prices drop and there are fixed price contracts between aggregators and flexibility providers, aggregator's margin gets squeezed.

Fifthly, in reality the aggregator might create more tailored products linked to the house temperature, where customers allow the aggregator to move within given temperature boundaries. This product will offer much higher customer comfort but will be much more difficult to model as temperature drops vary massively based on house insulation, house use, and outside temperature.

Lastly, there are always possibilities to increase the size of the fees. Flexibility providers might be able to offer more flexibility, i.e., reduce more often their heating demands. These fees can be also combined. A household with electrical space heating is likely to have electrical water heating as well. EV owners are likely to have batteries and every residential household typically has a fridge. These combinations can make it more interesting for the individual flexibility providers.

b. Revenues sources – wholesale market trading

For wholesale market trading, there is only one source of revenues – fees for changes in consumption. Wholesale energy costs vary a lot and DSR is likely to be participating only in high-stress periods with extreme spot prices. Example of such very high prices presented in Section II were 400 EUR/MWh, i.e., 9,750 CZK/MWh, for the day-ahead market. Intra-day market is not analysed separately as the weighted prices were shown to be very close to the day-ahead prices.

Using the flexibility potential calculations in previous sections, it is easy to calculate the per hour fee the linked to each flexibility provider. Assuming the aggregator would propose a "5 hours a month" flexibility product, Table 9 presents the fees linked to each flexibility provider.

Table 9. **Summary of the monthly fees per device from wholesale trading for extreme prices**, CZK

	Device	**per hour fee**	**5 hours / month product**
Residential	Heat pumps (space heating only)	7.3	36.6
	Convector heaters (space heating only)	7.6	38.0
	Water heaters	2.9	14.4
Commercial	Convector heaters (space heating only)	16.9	84.3
	Water heaters	12.8	64.0

Overall, these numbers are rather small, roughly 10 times smaller than for the ancillary services for similar level of discomfort. This is aligned with previous conclusion that the value for DSR lies in reserving the option to reduce consumption but not really in actively reducing the consumption. Since wholesale market participation would only include fees for activation, aggregators are likely to find it more valuable to participate with LV DSR on the ancillary market rather than on the wholesale energy market.

The approach to verify the business case for extra consumption during negative prices is similar. Example of such high negative prices presented in Section II were -30 EUR/MWh, i.e., -730 CZK/MWh. Such high negative prices occurred roughly once every month in the period from January 2019 to August 2021. To analyse the discharge potential, instead of the TDD-derived average hourly consumption, I need to assume average power input for the selected devices to estimate the excess power consumption on top of what devices are already consuming. The assumptions and results of the fees are presented in Table 10.

Table 10. **Summary of the monthly fees per device from wholesale trading for negative prices**, CZK

	Device	Assumed max power[7] (kW)	Average hourly consumption (kWh)[8]	per hour fee (CZK)
Residential	Heat pumps (space heating only)	4.0	0.8	2.4
	Convector heaters (space heating only)	12.0	0.8	8.2
	Water heaters	2.0	0.3	1.2
Commercial	Convector heaters (space heating only)	24.0	1.7	16.3
	Water heaters	4.0	1.2	2.0

The hourly fees, given the 1-per-month frequency also the monthly fees, are minimal and are unlikely to motivate LV customers to participate in such scheme. The fee size might differ if a Czech DSR aggregator would bid on the European market with higher penetration of renewables and hence higher frequency and size of the negative prices. Still, other market participants, such as MV DSR, are likely to capture this market with better unitary economics.

Overall, the wholesale bidding does not seem to be a relevant revenue vertical for LV DSR aggregation for now. Aggregators will likely prefer to use LV DSR in the ancillary services where they can collect fees for reservations. On top, wholesale energy market presents high variability which increases risk for the aggregators by paying fixed fees to the flexibility providers and receiving variable income from the market. For these reasons, these revenues will not be included in the business case.

c. Platform costs

To develop platform that integrates customer preference in terms of flexibility offered, allows trading these combined offers on the market, and then issues commands to flexibility providers will be a complex technology endeavour. However, aggregators will already do most of this work when aggregating the MV/HV commercial and industrial players. Extending this platform to LV appliances will not be easy but should be much cheaper than developing the platform anew.

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[7] The average device input was chosen from several devices offered online. But given the miniscule unitary fees, even higher average power inputs would not change the outcome.

[8] For heating devices, the average heating season consumption was taken. Using a zero consumption for the non-heating season will nevertheless not change the outcome.

Also, the TSO / market regulators are likely to provide part of the solution to facilitate easy access of third parties. Part of the IT systems will be operated by an independent entity to allow for transparent data recording and access by multiple aggregators. It is currently unclear who will be paying for this shared service – either aggregators themselves or the costs will be socialized among all power consumers in the regulated energy cost items. In this analysis, I assume socialization for simplicity. Lastly, all of these costs will be purely fixed overhead costs or capex investments that will not influence the unitary profitability.

On the other hand, customer management costs such as marketing, customer onboarding, and complaint resolution will directly influence gross profitability of the business. There will be also business risk costs and penalties for failing its commitments. If an electricity market player does not fulfil its expectations in terms of electricity demand or supply, OTE charges such player significant penalties. From April 2022, calculation of these penalties has been updated with multiple conditions linked to the current prices of wholesale energy, price of balancing energy, and size of the system imbalance (OTE, 2022b). In the simplest case, the penalty for causing a MW of the negative system imbalance is calculated as the maximum from the price of wholesale energy, price of the balancing energy, or marginal price of the aFRR balancing energy + 5.5 multiplied by the size of the system imbalance.

In practice, the price of the negative system imbalance varied a lot with several extreme values, as reported in the Annual market report by OTE (2022a). 88% of hours in the year 2021 (January-November) had the price of the system imbalance below 3,000 CZK/MWh. Further 11% of the hours had the price of the system imbalance between 3,000 and 10,000 CZK/MWh. Still, there were 52 hours with price of the system imbalance above 15,000 CZK/MWh and 6 hours with price above 30,000 CZK/MWh. This is more than 10 times higher than the price of balancing energy of 2,350 CZK/MWh. These instances of high prices for system imbalance are quite rare but an aggregator needs to create a cost buffer for these, even if part of the penalties it would be charged it could then extract from the individual flexibility providers that might have failed to deliver expected response.

To cover all these overhead costs, aggregators are charging a percentage of the revenues from the ancillary services to generate gross profit margin. These costs can naturally vary a lot between individual companies and niche markets within the aggregation business. Delta-ee (2018) calculated the average gross margin of electricity aggregators at 35%. These margins are likely to drop with growing scale and better unitary economics. For the analysis below, I am assuming 30% margin taken by the aggregator from any fees generated.

d. Unitary capex

Unless separate wiring is installed for each dispatchable device at customers premises to allow for electrical relay switching, the dispatchable device will need to have a smart component. This is likely to become a standard for any new device.

But unless this functionality is mandated by smart grid standards, a customer will face a decision whether to buy more expensive smart-enable device or a standard, cheaper device. The differences in costs between the standard and the smart-enable devices should be treated as capex investment depreciated over the expected lifetime of the devices.

On top, participation in the smart grid aggregation might require a purchase of dedicated device for communication with the aggregator platform. In ideal case, this functionality would be included in a smart meter or a smart home device. If not, unitary capex for this device needs to be included.

Any device participating in the ancillary services needs to be certified by TSO that it can provide such a service. Regular certification could be quite expensive and prohibitive for the residential flexibility providers. Hence TSO will need to launch a group certification for standardized devices where an external authority certifies that a certain device fulfils the standard TSO requires. Then the equipment manufacturer is responsible to ensure that the device maintains its properties that it was certified for. By extension, if one device fulfils the requirements, then a group of such devices can fulfil them as well with the same or even better accuracy.

The question "who invests" is not relevant for the overall business case. If the investor is the aggregator, depreciation of this unitary capex will decrease the fees payable to the flexibility provider. If the investor is the flexibility provider, he/she will implicitly deduct depreciation of this capex from the higher fees received, resulting in the same result, net of any tax implications.

Below, I run a sensitivity analysis on 3 potential unitary capex premiums: 5,000 CZK, 20,000 CZK, and 40,000 CZK which represent the difference between the normal and the smart-enabled device. The assumed device lifetime is 15 years, and the interest rate is 5% (sensitivity presented also for 3% and 7%). Results are presented in Table 11.

Table 11. **Equivalent monthly payments for an initial unitary capex**, CZK

	Annual interest rate		
Initial extra cost (CZK)	**3%**	**5%**	**7%**
5,000	35	40	45
20,000	138	158	180
40,000	276	316	360

Interest rate has relevant, but not drastic impact on the resulting equivalent monthly payments. For example, if the initial extra capex needed were 20,000 CZK, then 40% increase in interest rate (5% to 7%) leads to only 14% increase in the equivalent monthly payments. For simplicity, I use the 5% interest rate in all further analysis. Overall, the equivalent monthly payments for any capex investments seem quite sizeable, if compared with the fees for providing flexibility.

e. Unitary opex

Reliable and fast communication between the flexibility provider and the aggregator is necessary to tap into the more demanding and more profitable ancillary services. In ideal case, communication will be arranged through a smart meter or a smart home device. Alternatively, smart device can be connected directly to the Internet using a local Wi-Fi network. Either setup would prevent any extra opex communication costs. Any monthly communication fees, such as renting a machine-to-machine (M2M) data card, could negatively influence the business case.

In case of home batteries, there is an additional cost of charging the battery after discharge during activation. Average price of 4.7 CZK/kWh is assumed with a charge/discharge efficiency of 85%. Activation in this case is less profitable for the battery owner as he/she has to pay the full cost of electricity to charge, including the full distribution of renewables support fees.

V. Results – Flexibility providers renumeration sizing

Combining the outcomes of the previous sections, I present below the expected fee sizes to the flexibility providers. The size of the fees is equal to the revenues from ancillary services less aggregators' platform costs and unitary capex equivalent monthly payments. I disregarded the revenues from wholesale trading and unitary opex as discussed before.

Table 12 summarizes the monthly fees available to an average device user with either the 4+4 hours or the 12 hours products without any additional unitary capex. The fees range between 100 and 300 CZK per month for residential customers using either heat pumps or convector heaters, depending on the type of ancillary service and amount of flexibility offered. The fees for water heaters are much lower, ranging between 40 and 85 CZK per month. On the contrary, LV commercial customers have much higher fees ranging from 200 to 650 CZK.

Table 12. **Summary of the monthly fees for an average flexibility provider without any unitary capex – heating and water heating,** CZK

	Device	aFRR+		mFRR5	
		4+4 hours	12 hours	4+4 hours	12 hours
Residential	Heat pumps (space heating only)	210	289	107	147
	Convector heaters (space heating only)	218	299	111	152
	Water heaters	79	85	43	47
Commercial	Convector heaters (space heating only)	471	640	240	325
	Water heaters	299	378	164	207

Table 13 summarizes the monthly fees with the 20,000 CZK extra unitary capex investment with 5% interest rate. When accounting for this extra capex, the real renumeration for individual residential flexibility providers turns negative in most cases. This means that if this 20,000 CZK extra capex is required, providing flexibility will not be a money generating activity for most of the current residential device owners. The fees for commercial device owners remain positive but their absolute value dropped significantly. This indicates that even relatively modest unitary capex can destroy the profitability for most of the device owners.

Table 13. **Summary of the monthly fees for an average flexibility provider with unitary capex – heating and water heating**, CZK

	Device	**aFRR+**		**mFRR**	
		4+4 hours	12 hours	4+4 hours	12 hours
Residential	Heat pumps (space heating only)	52	130	-51	-12
	Convector heaters (space heating only)	60	141	-47	-6
	Water heaters	-80	-73	-115	-112
Commercial	Convector heaters (space heating only)	313	482	81	167
	Water heaters	141	220	6	49

All these fees are naturally outcomes for an average consumption for given device, as presented in Table 2 and Table 3. Household with higher or lower annual electricity consumption can proportionately scale up or scale down the size of the fees. Similarly to firstly onboarding the HV and MV customers, the high-consumption LV customers will likely participate first before the low-consumption customers.

I performed similar calculation for home batteries and EV chargers. The results are presented in Table 14. For simplicity, I only include results without any unitary capex.

Table 14. **Summary of the monthly fees for an average flexibility provider without any unitary capex – batteries and EV chargers,** CZK

Device	**aFRR+**	**mFRR5**
Home batteries (10 hours a day)	1,431	615
EV chargers (12 hours a day)	129	71

Using home batteries for flexibility seems like a promising approach given interesting fees available. However, this needs to be compared to the overall capital costs to install a battery as well as the replacement costs caused by frequent charge / discharge cycles. Most likely, installing a battery for purely ancillary services provision is not yet profitable as no such installations has yet occurred in the Czech grid. This can change quickly with the recently spiking FCAS prices. Still, providing FCAS from a home battery could be interesting supplementary revenues for batteries primarily installed to maximize self-consumption of PV.

VI. Results – Renumeration relevance testing

The size how of fees has been estimated. However, are these fees interesting at all to the Czech customers? I have conducted qualitative and quantitative research to estimate fees relevance as well as other hidden motivations and barriers for offering LV demand side flexibility on the market.

This relevance research was not conducted for all the examples calculated in the previous sections. Firstly, I focused only on households and not on commercial customers. Households are relatively unified group of customers. On the other hand, LV commercial customers can represent quite a broad spectrum from small shops to restaurants, small hotels, or workshops. Estimating fees relevance for this group would require much more sophisticated segmentation and is beyond scope of this thesis.

Secondly, I run the research only for heating and water heating customers. Even though batteries and EV chargers are likely to be relevant flexibility providers in the future, the current owners of these devices are not the same as the future owners of these device if a scale is to be reached. Currently, batteries and EVs are owned and operated by higher socio-economic class while to reach scale, middle class needs to be involved. Testing fee relevance on the current owners would hence not yield relevant results on the future owners. Finally, quality of data and estimates is highest for the heating and water heating customers as they have their own dedicated synthetic profiles.

a. Methodology overview

First insights were collected in qualitative research through focus group discussion in April 2022. A group of 7 consumers with either electrical heating, heat pumps, or electric water heating were interviewed to obtain deeper insight in how well they understand the concept of flexibility provision, and what would motivate them or prevent them from participating in offering flexibility. Even though this focus group discussion did not aspire to come from a representative sample, it was useful to understand deeper motivations and to shape the questions in the quantitative research.

Consequently, a survey form was developed to gauge the interest of typical Czech electricity consumers to participate in the flexibility offering. The data were collected from a representative sample of Czech population above 18 years old. The total sample size was N = 2,538 respondents and was drawn from the Czech National Panel database. The representativeness extended over age, gender, age x gender, education, employment status, region, and size of the settlement respondents live in. The only exception to representativeness of the sample was education distribution. The sample contained 5.3pp less people with basic or vocational education and 2.5pp and 2.9pp more people with high school and university degree, respectively. This difference to representativeness is reflected when comparing the sub-samples to representative population. On top, information on income group and socio-economic classification were listed for each respondent. The socio-economic classes follow the standard ABCDE classification (Nielsen Admosphere, 2021).

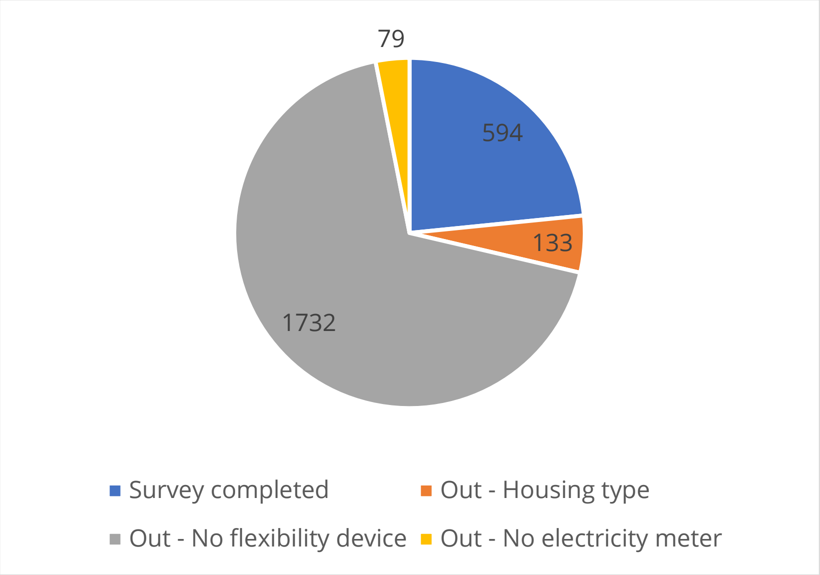
The data were collected during May 2022 using the computer-assisted web interviewing (CAWI) online method. Both focus group discussion and survey were administered by the NMS Market Research agency.

Only the people fulfilling the conditions below were included in full the survey:

- Respondent lives in a house or a flat (no temporary or group accommodation),
- Respondent uses electric devices as the main source of heat or the main source of hot water in their primary accommodation,
- Respondent owns either heat pump, electricity accumulation water heater, or an electrical heating device (convector heaters, electric boiler, or electric heating foils),
- Respondent or his/her household members have direct contract with an electricity supplier and DSO (so that he/she can make decision about flexibility provision).

From the full sample, 77% of people were screened out. The main reason was not owning an electricity device usable for flexibility. The breakdown is presented in Figure 26. Total of 594 qualified respondents completed the survey.

Figure 26. **Survey respondents by outcome**, no. of respondents



The survey asked the qualified respondents for their devices and electricity consumption. Then respondents were presented with a tailor-made offer, asked for their interest in such offer and to identify the main motivators and barriers to participate in providing flexibility.

Given the large sample and individual data entry by the respondents, I cleaned the data from several recurring mistakes that could be easily identified. In 4 instances, respondents confused units for consumption, entering either MWh instead of kWh or vice versa. Similarly, 1 respondent swapped annual for monthly energy bill. More importantly, several respondents reported inconsistencies in ownership of electrical flexibility devices and their primary source of heating. I moved 7 people from a Electric heating group to a Heat pump group since despite claiming to use electrical heating as their primary heating source, they reported only ownership of a heat pump. Also, people owning either a heat pump (8 respondents) or a fixed electrical heating (59 people) as a secondary source of heat were included. Results for these are reported separately if there is a difference in outcomes.

b. Qualitative research outcomes

The topic of electricity and in general energy consumption was highly relevant to the participants in the focus group discussion given the rising prices of energy and recent bankruptcies of several energy suppliers. Participants were explained the medium-term plan to introduce flexibility programmes for households and were presented an offer (4+4 hours, 12 odd/even hours) with specific renumeration for participation.

The first insight from the discussion was that the product is relatively difficult to understand. Participants initially struggled to fully grasp the concept. The following concerns were raised:

- *Risk of turning off all electricity devices*. Participants needed multiple reassurances the product concerns only electric heating and water heating.
- *Fear of overall shortage of electricity supply*. Participants needed reassurance that this offer will not constrain their overall consumption, but rather move the consumption in time to 'flatten the curve'.
- *Maximum duration of consumption constraint*. Participants needed clarity that the duration of the consumption will be short (15-30 minutes), not leading to big drops in temperature in the house or prolonged periods without hot water.
- *Voluntariness of the offer*. Participants raised concerns about being forced to constraint their consumption by regulation.
- *Fairness of the consumption constraints*. Participants needed reassurance that also other electricity consumers, such as industry, commercial establishment, or electric vehicle owners, will participate in such flexibility schemes.
- *Technical functionality*. Participants needed clarity on how their devices will be managed by an external party and under which conditions they will relinquish control over their devices.

- *HDO cannibalization*. Participants needed clarity on how the proposed system will work alongside the existing ripple control system as their heating and water heating devices are already turned off for several hours per day.

These concerns were addressed when presenting the offer in the follow-up quantitative survey. On top, the discussion participants identified several features that were desirable from their perspective and would increase their likelihood to sign up.

- *Ability to opt-out for a short-term period.* Participants desired option to opt out in case of emergency, such as having an ill child at home that needs higher temperate or hot water.
- *Tailor-made time settings.* Participants desired option to adjust the offered flexibility hours based on the family regime.
- *Non-monetary benefits*. Participants desired preferential treatment in their standard electricity products if they were to participate, such as offering a longer electricity price fixation.
- *Regulatory oversight.* Participants desired oversight by a trusted regulatory body to prevent scams and bankruptcies of companies having control over their electricity consumption. In ideal case, the party offering them the flexibility product would be a trusted energy supplier.

The overall findings were roughly aligned with the Ecogrid 2.0 experience gauging customer motivation. There were also cases of participants with “a fundamental aversion against external intervention/control in their home: Fear of ‘loosing electricity’ or an intrusion in their private sphere” (Jacobsen & Pallesen, 2017). In our Czech setting, there were on top cases of fundamental aversion towards anything linked to ‘ecology’. The concept of the entity of an aggregator was also relatively difficult to communicate to the participants. Again, following Ecogrid’s 2.0 example, I decided that “it will therefore often be advantageous to only use (aggregator) as an internal technical term” (Ecogrid 2.0, 2019).

Based on the discussion, we defined the main motivators and barriers to participate in flexibility provision, to be quantified in the research survey. The main motivators are:

- *Financial motivation* – reward for availing the devices.
- *Ecological motivation* – helping the electrical grid to transition to low-carbon sources.
- *Security motivation* – helping the grid to ensure grid stability.

The main barriers are:

- *Lower comfort* – loss of full control over heating and water heating.
- *Offer complexity* – lack of clarity on when, how, and which devices will have reduced consumption.

- *Privacy intrusion* – relinquishing control over consumption to a 3rd party.
- *Trust in such offer* – issues to trust the company and the offer itself.

c. Quantitative research outcomes

Even though the initial sample was collected in a way to be representative of the Czech 18+ population (expect for education), the sample of 594 qualified respondents might not be. I compared the sample frequency distributions across the 7 representativeness categories with the predicted frequency distribution defined by the Czech Statistical Office (2020), using the standard χ^2 test for independence with 5% confidence level. The statistics for age, gender, age x gender, and employment status remained representative of the Czech population. On top, education level in the qualified sub-sample remained unrepresentative in similar way as the full sample. However, region and size of the settlement were found not to be representative of the Czech 18+ population.

The details are presented in Figure 27 and Figure 28. In terms of regions, inhabitants of Prague, South Moravian region, and Moravian-Silesian region are under-represented, which are exactly the regions with the 3 biggest cities in the Czech Republic. On the other hand, inhabitants of Central Bohemian, South Bohemian, and Plzeň regions are over-represented. This indicates that people living in large cities are less likely to qualify than those living in smaller villages. This is clearly confirmed in Figure 28 but should come as no surprise. Households in larger cities typically have good connectivity to central heating or the gas pipelines which means they are less likely to have the necessary flexibility device to qualify.

Figure 27. **Representativeness comparison for regions**

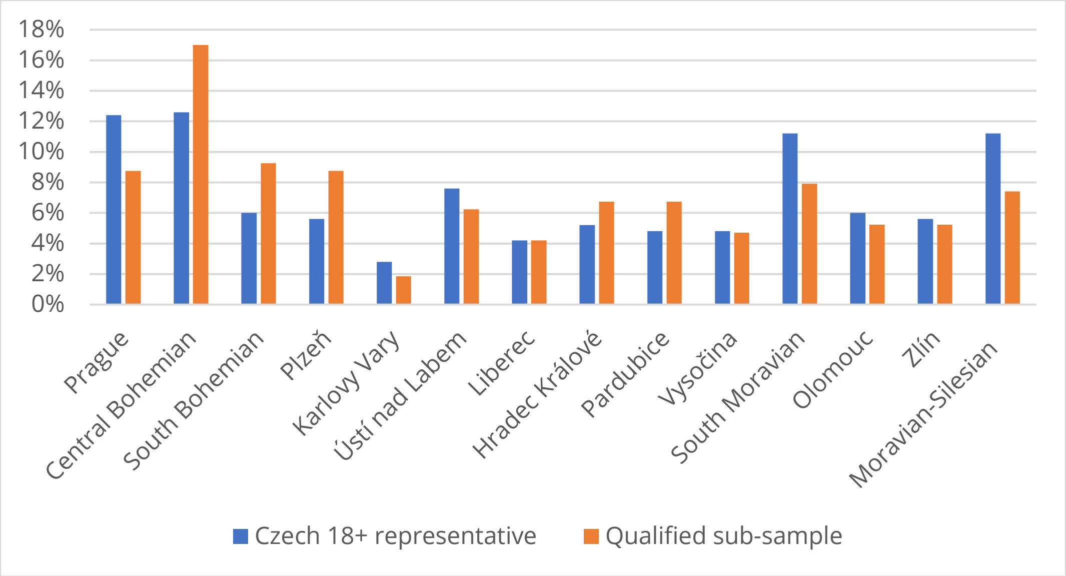
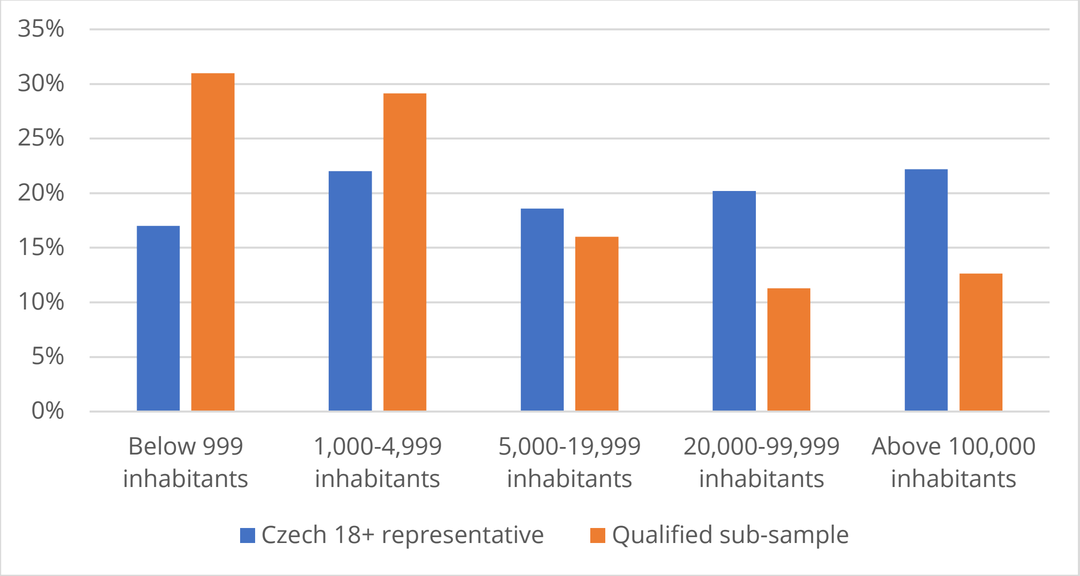


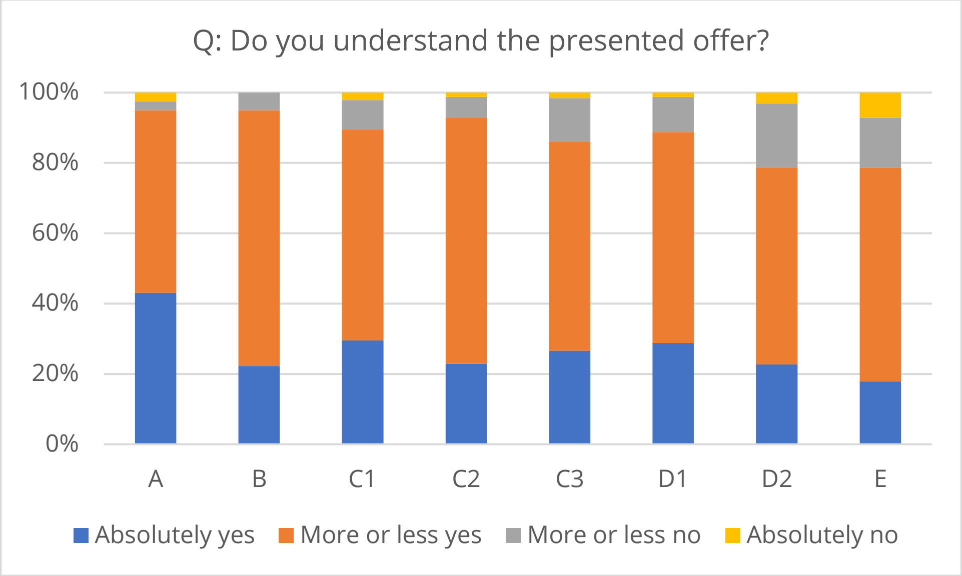
Figure 28. **Representativeness comparison for size of the settlement**



As during the theoretical fee size calculation, I split the qualified sub-sample into 3 groups for further analysis based on the device used: electrical heating (38% of the sub-sample, N=223), heat pumps (16%, N=93), and electrical water heating (47%, N=278). The differences between these groups are as expected. Heat pumps are more common for households living in houses and in smaller settlements. Heat pumps are also much more prevalent among higher socio-economic classes, most likely due to high investment costs required. Electrical water heating is much more common for households living in apartments and in larger cities.

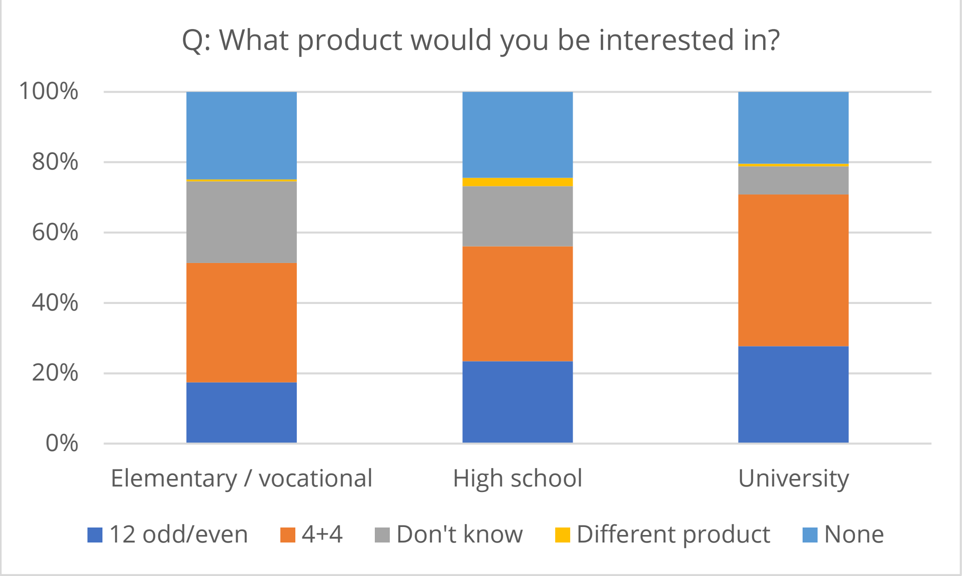
As mentioned previously, respondents entered their power consumption in the survey. Based on this response and the type of device they own, the survey presented them a tailor-made offer for monthly fees they could receive from participation in the flexibility offering, either in the 4+4 hours or 12 odd/even hours. For those who did not provide their power consumption, average Czech household consumptions for given devices were used. Firstly, respondents were asked if they are clear on the proposed offer. 89% of respondents said they are ‘fully clear’ or ‘more or less clear’ what the offer means. 9% claimed that the offer is partially unclear and only 2% said the offer is totally unclear to them. There is an obvious socio-economic pattern in level of understanding of the offer. Higher classes (A-C2) have much better understanding of the offer than the lower classes (C3-E), as visible in Figure 29. Younger people also typically understood the offer better, even when controlling for socio-economic classification.

Figure 29. **Understanding of the flexibility offering**



Secondly, respondents were asked if they would be interested in taking up one of the products (4+4 hours or 12 odd/even hours). People not understanding the product were excluded from further analysis. Over 58% of people were positive about accepting one of these offers. The remainder was either not interested (24%) or was unable to answer (17%). From those interested in the offer, 36pp preferred the smaller 4+4 hours product while 22pp preferred the bigger 12 odd/even hours. Quite surprisingly, the answers did not present any difference between socio-economic classes, age groups, or types of devices owned. The only clear pattern displayed education level; those with university education were willing to accept the offer by 20pp more than those with only elementary or vocational education. Also, more educated people were willing to offer more hours of their devices. Figure 30 presents the split.

Figure 30. **Acceptance to participate in the flexibility offering**



Consequently, people were asked what monthly fee they would require to participate in either the 4+4 hours or the 12 odd/even hours offering. The reported fees were normalized to fit with an average household consumption per device as reported in Table 2. The histograms of required monthly fees for individual device types are presented in Figure 31, Figure 32, and Figure 33. For simplicity, I only report only fees for the 4+4 hours product.

People reporting 0 fees are nearly always those that would not accept the offer under any condition, as assessed from further answers and comments left by the respondents. They represent 9-10% of each device type. These are quite similar to the people requiring very high monthly fees such as those above 2,000 CZK per month. These represent around 20% for electrical heating and heat pumps and 13% for electrical water heating. Respondents with electrical water heating typically require lower compensation. 45% of those would be happy with a fee below 300 CZK per month. These fees would be accepted only by about 18% of respondents with electrical heating or heat pumps.

Figure 31. **Histogram of required fees (CZK/month) to participate in flexibility – electric heating (4+4 hours)**, no. of respondents

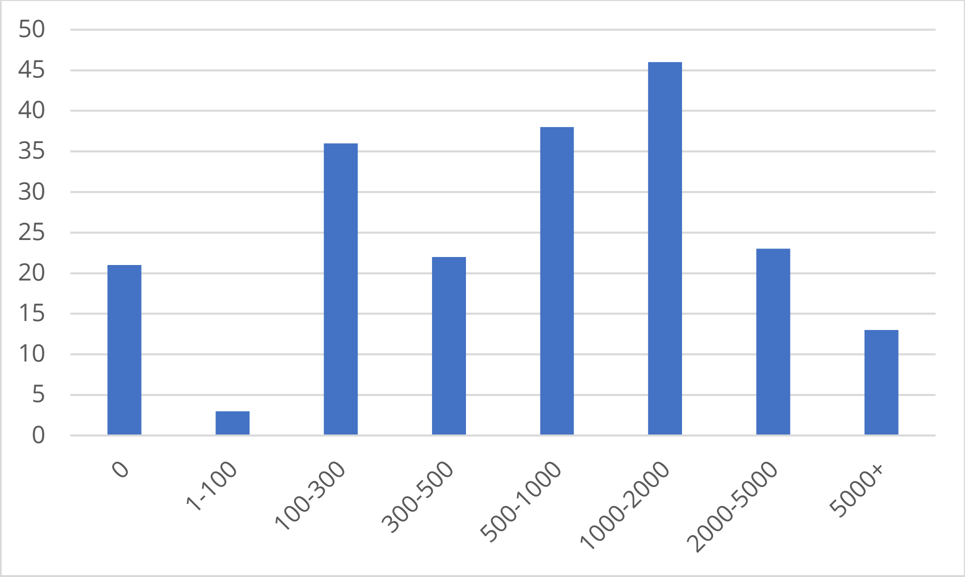


Figure 32. **Histogram of required fees (CZK/month) to participate in flexibility – heat pumps (4+4 hours)**, no. of respondents

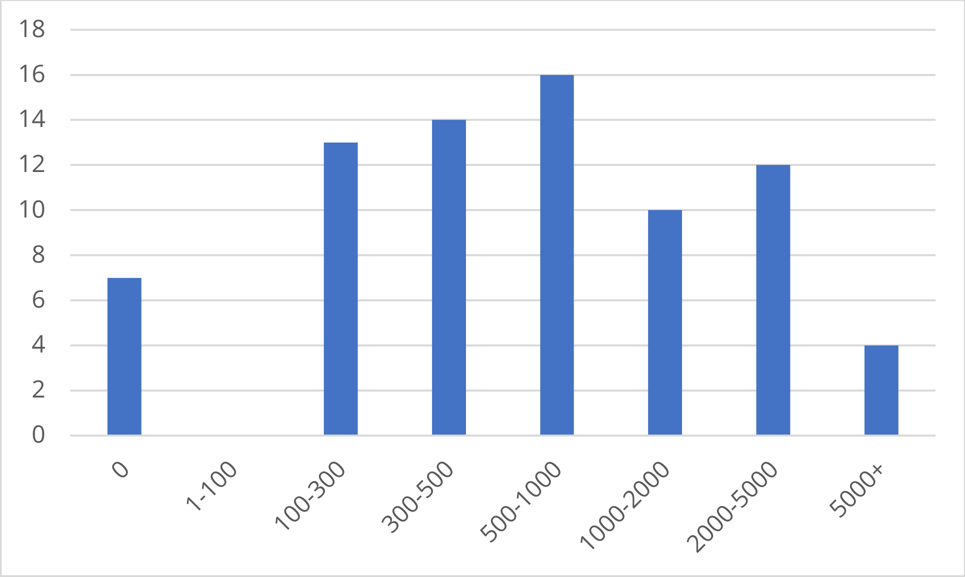
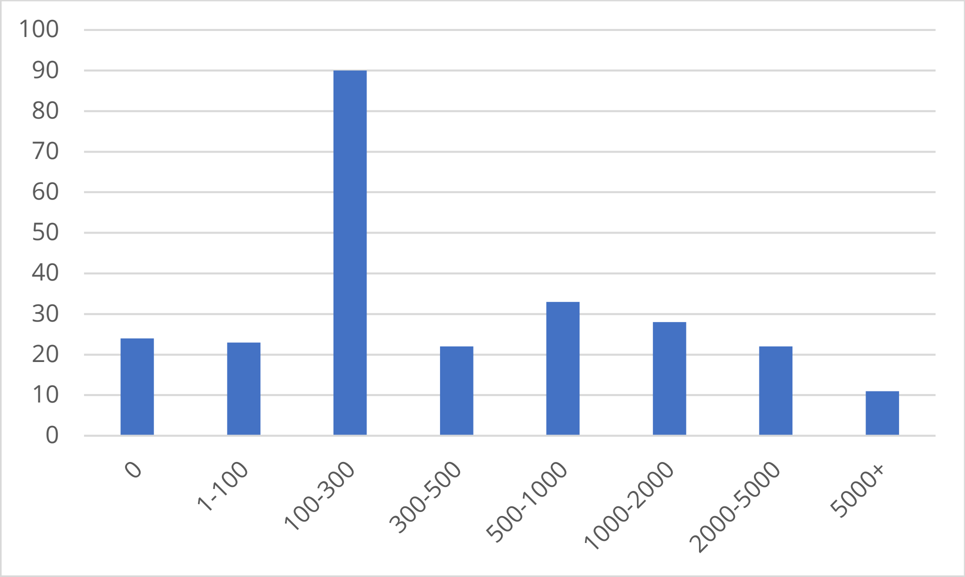


Figure 33. **Histogram of required fees (CZK/month) to participate in flexibility – electric water heating (4+4 hours)**, no. of respondents



If I look at the sample of respondents who understand the offer and are willing to consider at reasonable fees (i.e., excluding those with 0 value or fee above 2,000 CZK/month), I end up with 393 respondents, which is exactly two thirds of the qualified sub-sample of 594 respondents. For those, I present in Table 15 the mean fees, median fees, and standard deviations. Median fees of 470 CZK/month and 400 CZK/month are required for electrical heating and heat pumps, respectively, while for electrical water heating the median required fees are only 195 CZK/month. The reported fees exhibit large variance, when reduction of the fees by one standard deviation brings the values close to zero.

Table 15. **Statistics of required fees for interested respondents**

		Electrical heating	Heat pump	Electrical water heating
N	#	140	55	198
Mean	CZK/month	584	512	322
Median	CZK/month	470	400	195
s. d.	CZK/month	408	394	340

This implies controversy of this topic – some people are satisfied with quite low fees, drawing motivation from other factors than financials, while others are opposed to the idea and would require very large fees to participate in such offering. So finally, I look at the main motivators to and barriers to participate in the flexibility offering. Respondents were asked to rate the 3 identified motivators and 4 identified barriers from the qualitative research on scale from 1 (lowest priority) to 10 (highest priority). The results are presented in Figure 34 and Figure 35.

Figure 34. **Rating of motivators to participate**, points

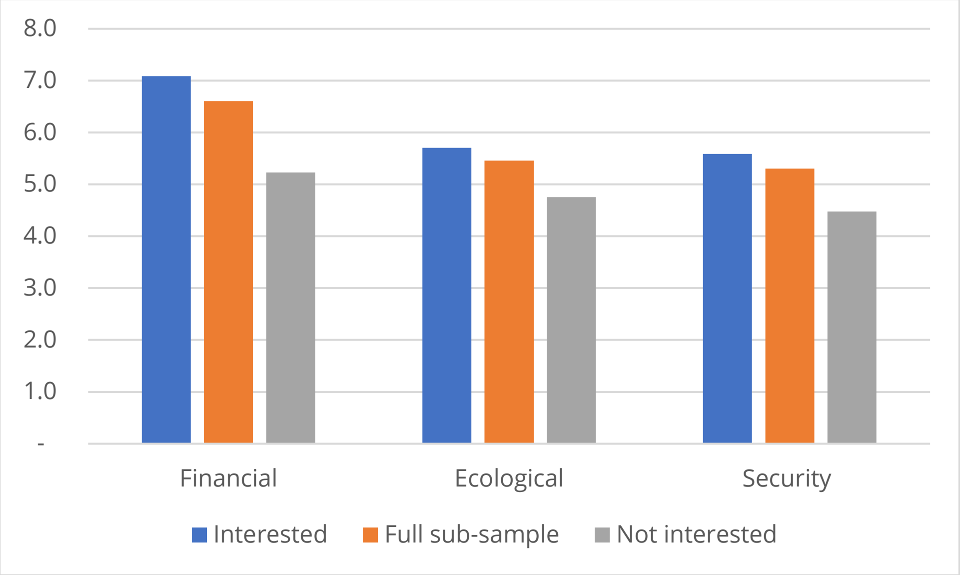
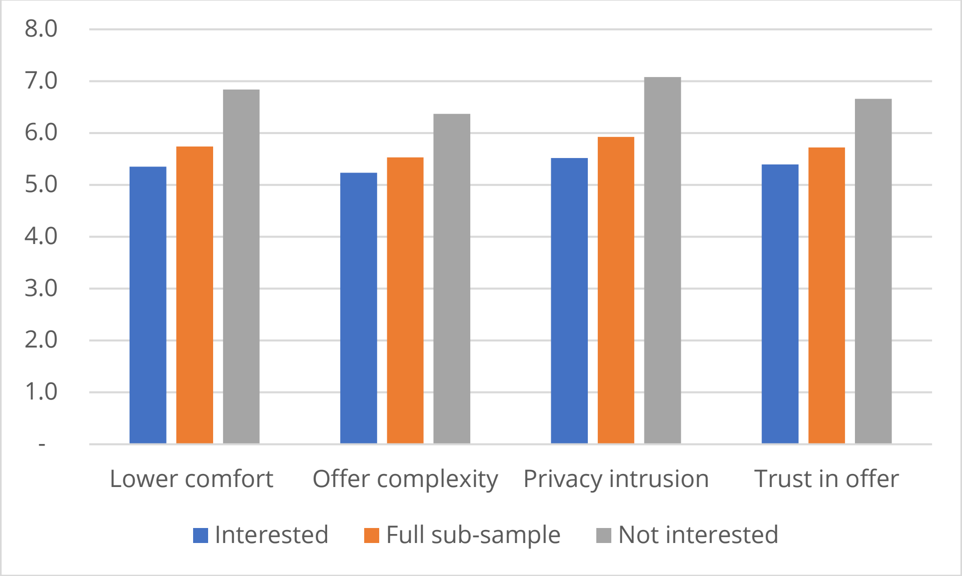


Figure 35. **Rating of barriers to participate**, points



Overall, the differences in averages between motivators and barriers are not that striking. Some factors are very important for some people while not for others. Still, financial motivation seems to be overall most important to push people to potentially sign up. On the other hand, lower user comfort and loss of privacy seem to be the biggest barriers preventing people from participating. There are no significant differences in the motivators and barriers between the different devices used. On the other hand, there are several interesting differences in other variables. Younger people (18-24 years) are reporting 1.7 points higher ecological motivation than older generation (45+ years). Among those not interested in the offer, older generation (45+ years) is reporting 2 points higher barrier from privacy intrusion than younger generation (18-24 years). University graduates also much less commonly report as a barrier complexity of the offer or trust in the offer itself.

In addition, some patterns in groups of respondents emerge. There are people concerned primarily about environment. 72 people rated ecology as a very important factor (7 or above) while requiring normalized fees below 200 CZK per month for the 4+4 hours product. This represents 14% of the sample of respondents who understood the product. There were also 42 people who rated finances as the motivation (7 or above) while disregarding ecology or security motivations (4 or below). This represents 8% of the sample, which is surprisingly not that high. People do tend to consider other motivations besides financials.

Respondents also left comments to further explain their motivations or limitations to participate. Similarly to the qualitative research, a significant part of the sample expressed their strong view against any changes. They are suspicious of the system and dislike nudges from any environmental policies. This group resembles the reported 10% of people would not accept the offer under any circumstances. Second clear group was having comfort concerns, mostly around availability of hot water or ability to turn on heating in critical situations. This group resembles the roughly 20% of the sample who require very large compensation, which would in essence make them irrelevant for any aggregator. Lastly from the commentary left by the respondents, they asked for further clarification on how the proposed offer would work with existing HDO system. This held true especially for users of electric water heaters who under current HDO scheme have only 8 hours per day for water heating and hence stated sensitivity towards any curtailment of such time.

VII. Conclusion

This thesis estimates economic feasibility of low-voltage demand side response aggregation in the Czech electricity market. With gradual phase out of large, fossil fuel power plants, a need arises for new sources of ancillary services. Enabling participation to subscale LV players presents a significant opportunity given their overall consumption in the Czech grid and their ability to delay consumption. Aggregators in Western Europe are already piloting LV demand side response while the first MV aggregators started providing ancillary services to the Czech grid in 2021.

Overall, the individual business case works for most of the devices, especially for the space heating and water heating as well as for home battery systems. Owners of these devices could receive monthly fees ranging from 200 to 300 CZK per month for space heating and around 80 CZK per month for water heating. The fees available for home batteries are much larger, above 1,000 CZK per month, given bigger immediate output the battery can provide. Much larger fees will be available for LV commercial establishments. For space heating and batteries, participation in flexibility provision will likely be limited only to winter months where there is an actual power demand for space heating or spare battery capacity. Given the large variability in ancillary market prices and changes to ancillary services bidding and dispatching from April 2022, these business cases should be recalculated with the new data once enough information is accumulated.

Both qualitative and quantitative surveys confirm interest of the residential customers to participate in flexibility offering. Over 58% of people stated interest in the tailor-made offer given their current consumption and the device they own. Some people are motivated by financials, other by helping the grid to move to a low-carbon production in a stable way. On the other hand, around 30% of potential customers clearly oppose the idea of providing their device to any flexibility offering, mostly due to general aversion to any change and concerns over significant comfort reduction. Also, the concept of flexibility provision is not easy to explain to the potential customers while their acceptance of the offer critically hinges on good understanding, especially the difference between activation and reservation for ancillary services. These concerns need to be taken account by any new aggregator when designing offers to customers.

LV demand side aggregation seems to have value in ancillary services. Reserving the capacity means maintaining status quo for the customers. Only the much less frequent activation then causes disruptions to customers' power consumption. This is contrary to the ancillary services by large power plants which need to reserve part of its output for this service and cannot utilize it for other productive activities. With the recent changes in dispatch and bidding for ancillary services, LV DSR aggregation can play a relevant role as a 'last resort' ancillary service with cheaper reservation and expensive activation. On the other hand, bidding negative consumption on the wholesale market does not seem to present an interesting opportunity as each successful bid is connected to a demand reduction on the side of the flexibility provider. Fees from the wholesale bidding without any reservation fees seem to be insufficient for any reasonable financial motivation.

Expansion of attractive DSR aggregation could result in virtuous circle of adoption and benefits. The aggregation offer might persuade more people to invest into more or bigger batteries in their houses or to choose a dispatchable electricity device over non-dispatchable (missing smart functions) or non-electricity device (gas heater). Higher number of flexibility providers could help to mature the flexibility market and further improve profitability of the flexibility offerings.

Introduction of LV DSR aggregation is still currently hindered by several technical limitations. It remains unclear what new devices will be needed. In ideal case, participation will only require internet connectivity to an already smart-enabled device. Any new unitary capex outlays significantly constrain attractiveness of the business case. Clear differentiation between the aggregator command flexibility, future planned dynamic tariffs, and current ripple control system needs to be outlined and clearly communicated to the customers. Lastly, treatment of rebound effect and proper methodology to calculate baseline consumption needs to be agreed and codified. Much more data will be needed to track performance of the LV demand side response and even create specific offers to customers.

Overall, LV dispatchable devices present a relevant technology to integrate into the Czech ancillary services market in the medium term. More than half of the eligible households could be interested to participate which could create a big pool of flexibility for the eventually decarbonized power grid.

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