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RESIDENTIAL DEMAND RESPONSE: FINANCIAL COMPENSATION FROM CAPACITY MARKETS

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Residential demand response: financial compensation from capacity markets

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Motivation and participation

Reliable electricity transmission requires supply and demand to be in constant balance. Satisfying this balance for a commodity that is difficult to store, like electricity, is quite a challenge. Especially so, when considering that we are all free to use electricity as we please and that any power plant or interlink to a neighboring country may fail at any time, thus causing a large deficit or surplus. The converged-upon solution for managing this delicate balancing act is to utilize trade on sequential electricity markets, with the intent of aligning supply and demand as well as possible before the time of delivery.

The increasing share of renewable energy sources, like wind and solar, is nonetheless causing significant supply fluctuations that require additional green flexibility to help align supply and demand. Residential demand response provides one such source of additional flexibility, where households shift consumption in response to financial incentives to help keep the balance. Here, we will briefly go over the structure of the sequential electricity markets and investigate what the size of this financial compensation could be for one of the markets, namely the reserve market.

Balancing supply and demand with sequential markets

Electricity companies are responsible for acquiring as much electricity as their customers use, a responsibility known as "balancing responsibility." Companies fulfill this responsibility by adjusting their production or by trading. Trading is used to both manage price risks with futures on financial markets (up to 10 years in advance) and to buy and sell electricity on power markets or through bilateral agreements. Most of the electricity in Finland (≈ 70 % of the total volume) is traded on the hourly day-ahead market, also known as the spot market, where electricity is traded one day in advance (see Fig. 1). Electricity companies thus make day-ahead consumption and production forecasts with an hourly resolution (15 minutes in the future) for their customers and potential production units, respectively, and try to trade away their imbalances. Potential deficits or surpluses from unexpected demand or production events within the day can later be traded on the intraday market (≈ 2.5 % of the total volume), although at a more unfavorable price on average for the party being forced to trade to keep their balance. Any remaining imbalance at the time of delivery is finally balanced out through trade with Fingrid on the reserve market (< 1 % of the total volume). Fingrid constantly makes the last fine adjustments needed to maintain the balance by operating reserve units that can increase or decrease supply as needed, but again, at an additional cost for the party being forced to trade to keep their balance.

The reserve market is surprisingly complex, with multiple capacity and energy product types, even though the energy traded is less than 1 % of Finland's total. This complexity mainly reflects the fact that imbalances during delivery can occur for many reasons. Actual production and consumption might not match predictions, and various failures might occur at any moment. Consequently, the reserve market must handle everything from consumers using slightly more electricity than predicted to a ship's anchor breaking an interconnector to a neighboring country. The capacity product types (FFR, FCR-D, and FCR-N) provide reserves that can be quickly activated (within seconds or minutes) to restore balance in response to minor fluctuations or temporary disturbances, whereas the energy

product types (aFRR and mFRR) cover longer periods (up to hours) of a surplus or deficit resulting from prediction errors or failures. The split into capacity and energy products also reflects how providers are compensated. Providers of capacity reserve products are compensated irrespective of whether the asset is used, whereas providers of energy reserve products are compensated for the contributed energy.

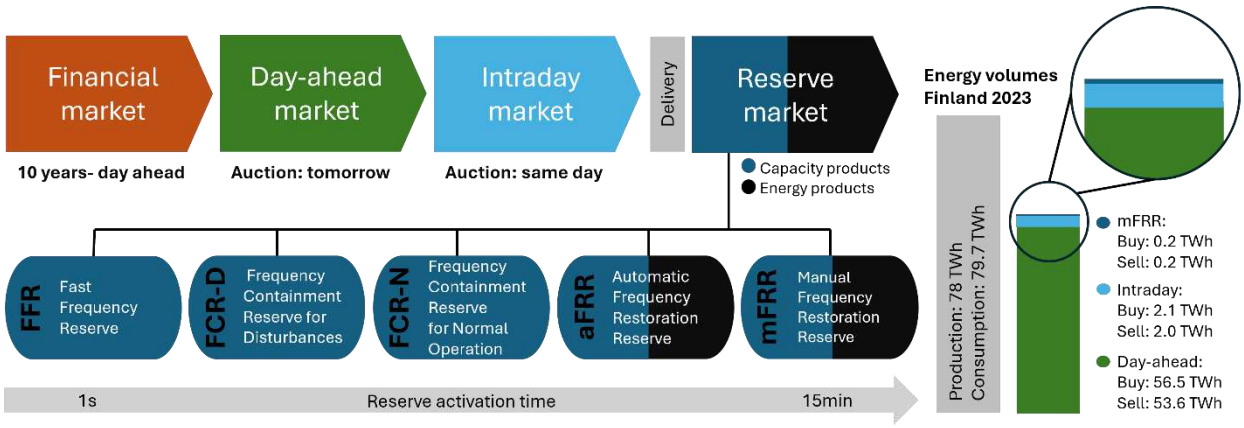

Figure 1. Electricity is traded on multiple sequential markets. Data obtained from Fingrid's Open data platform and from the National Report on the state electricity and gas markets in Finland in 2023.

Potential for residential demand response

The system of sequential electricity markets for balancing supply and demand creates both opportunities and challenges for residential demand response. Uncoordinated or unpredictable demand responses from residential consumers to already-settled spot prices can create large imbalances for their electricity companies, as their forecasts will be wrong. The imbalances must be balanced at an extra cost on the intraday or reserve markets, leading to extra costs for consumers at the end of the day. On the other hand, coordinated or predictable demand responses can lead to financial profits for both the electricity companies and their customers. These profits may derive from 1) shifting usage to times when supply is more plentiful, 2) decreasing balancing costs for the electricity companies, and 3) helping others keep their balance by selling flexibility to the intraday or reserve markets. Here, we focus on potential profits from selling flexibility as capacity products on the reserve markets. Individual households cannot participate in these markets alone due to the minimal power limit imposed by Fingrid, but participation can be enabled through aggregators that combine demand responses from multiple households.

The three capacity reserve types (FFR, FCR-D, and FCR-N) can be split into four products (summarized in Table 1) based on the type of regulation they perform: up-regulation (↑), down-regulation (↓), or symmetric. From a consumer's perspective, up-regulation corresponds to dropping a load, down-regulation corresponds to adding a load, and symmetric corresponds to having the capacity to do both. For example, participation in FCR-D↑ corresponds to receiving financial compensation for being ready to drop a load with a few seconds' notice if needed. Traditionally, FCR-N has been considered the most favorable product for residential demand response due to the lower minimal bid size (0.1 MW) and the longer response time. However, strictly resistive loads like heating elements could also respond fast enough to meet the requirements for FFR and FCR, but the minimal bid size of 1 MW requires an aggregator that pools demand responses from hundreds of households, whereas tens of households are enough for FCR-N. Fingrid nonetheless only procures FFR services during part of the year, mainly during the summer when households have few loads to drop, thus making FCR-D and FCR-N the main products of interest for residential demand response.

Table 1. Capacity reserve products offered by Fingrid

Product	FFR	FCR-D↑	FCR-D↓	FCR-N
Response time	1 s	seconds	seconds	minutes
Min. bid size	1 MW	1 MW	1 MW	0.1 MW
Regulation	Up	Up	Down	Symmetric
Agg. households	Hundreds	Hundreds	Hundreds	Tens
Procured	Summer mainly	Year-round	Year-round	Year-round
Activated	Rarely	Rarely	Rarely	Periodically

The potential financial compensation for households selling FCR-D and FCR-N products can be estimated from their yearly energy consumption and available heating elements. FCR-N and FCR-D↑ both require that a load can be dropped. A theoretical upper bound for the profit is thus obtained by assuming that all consumption could have been sold to the reserve market at the prevailing FCR-D↑ and FCR-N market prices. A rough estimate for this bound can be calculated by simply multiplying the yearly consumption by the average market price of each product. The yearly consumption for a typical household in Finland is 10 000 to 20 000 kWh a year, and the yearly average prices for FCR-D↑ and FCR-N were 1.7 and 4.6 c/kW/h during 2024, respectively. The compensation could then, at most, be almost a thousand euros per year (with FCR-N). However, a few hundred euros is a more realistic upper bound in practice, considering that 1) the price peaks for these two products occur during early summer (see Fig 2a) when consumption is low, 2) not all of the consumption can be sold to the reserve market, and 3) the profit would have to be shared with an aggregator.

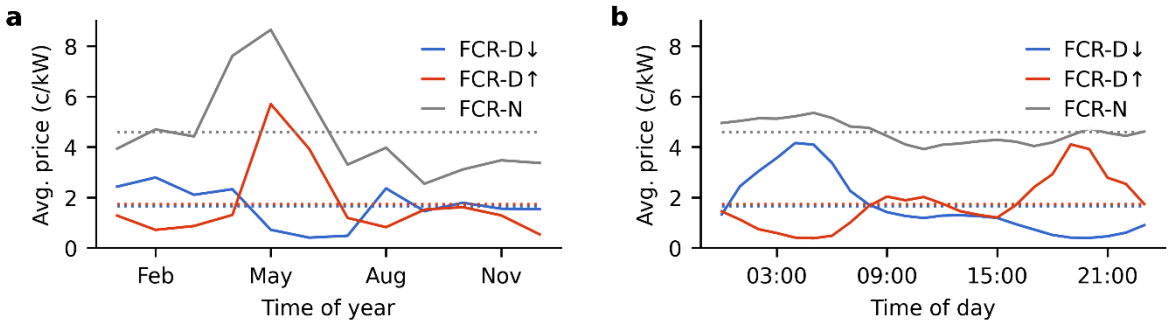

Figure 2. Average capacity product prices for 2024. ***a)*** *Average price per month.* ***b)*** *Average price per hour of the day. The dotted lines denote the yearly average price. Prices are given with VAT 0%, and the data is obtained from Fingrid's Open data platform.*

The potential profit from FCR-D↓, in turn, depends on the total power of idle loads that could quickly be turned on if needed. In a household, these are typically resistive loads like heating elements used for direct electrical heating, heating elements in a sauna, auxiliary heating elements in heat pumps, heating elements for pools, etc. Many households, therefore, have a theoretical potential to activate 5–10 kW quickly if needed. The average price for FCR-D↓ during 2024 was 1.7 c/kW/h, meaning that having 7.5 kW available year-round could bring roughly a thousand euros. However, the price peaks for FCR-D↓ correlate with when heating elements for direct electrical heating would be used (winter and nighttime, see Fig2a & b) and thus are not available for the reserve market. A more realistic upper bound for the potential profit is, therefore, closer to a few hundred euros when considering both the availability of the heating elements and that the profit again would have to be shared with an aggregator.

The same capacity can only be sold to one of the products on the reserve market; the total potential profit, therefore, corresponds to the maximum that can be obtained from a single product or by splitting available capacity into multiple reserve products. The potential profits of a few hundred euros from either FCR-N or FCR-D↓, therefore, correspond to a first rough realistic estimate of the

potential profits for households selling flexibility to the reserve market. However, one would still have to estimate the potential profits from contributing with energy products, aFRR or mFRR, instead of capacity products, as these could yield better profits.

Part of a larger service or product

Although residential demand response can have a significant stabilising impact on the electrical grid as a whole, a recurring challenge is that the financial compensation per household tends to be fairly small. Especially so when considering that participation requires the installation of some form of hardware to automate control of certain loads, and that participation in the reserve market requires the owner to give up control of the load during sold hours. However, the potential profits from the reserve market can be combined with potential profits from providing demand response on the day-ahead market, which can be accomplished through the same hardware. As a result, it is likely that future residential demand response products and services will try to sell the flexibility that demand response brings to multiple markets by aggregating demand responses from many households. This multi-market approach could potentially generate sufficient incentives to cover the initial investment for households and motivate participation in residential demand response.

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