***THE ECONOMICS OF EXPLICIT DEMAND-SIDE FLEXIBILITY IN DISTRIBUTION GRIDS***

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## Overview

The Clean Energy Package (CEP) Directive (EU) 2019/944 calls on the Member States to develop regulatory frameworks that incentivise distribution system operators (DSOs) to consider the use of flexibility as an alternative to grid expansion. DSOs will have to develop and publish network development plans that make a trade-off between the use of flexible resources and system expansion. How this will be implemented is one of the main open issues in the evolution of electricity markets in Europe (Meeus, 2020).

There are only a few studies that focus on this trade-off. BMWi (2014), a study for the German energy ministry, finds that allowing DSOs to curtail up to 3% of distributed generation (DG) would save about 40% of the network expansion cost. ENEDIS (2017) considers the costs and benefits of six flexibility options, on both the demand and supply sides, and finds that they may provide critical net gains by 2030. At the EU level, CE and VVA Europe (2016) developed an impact assessment report for the European Commission that estimates up to €5 billion annual savings in the EU by avoiding distribution investments towards 2030 from both demand and supply sides flexibility.

In the academic literature, Spiliotis et al. (2016) propose a model that assesses the trade-off between grid expansion and demand and DG curtailment. They find that for a congested 24-node radial distribution network, all physical expansions could be avoided with 12% flexible demand. Klyapovskiy et al. (2019) consider flexibility from the demand side and in terms of technical solutions using grid assets and compare them to traditional reinforcement over a period of four years. Asensio et al. (2017) develop a bi-level model for the distribution network and renewable energy expansion planning under a Demand Response (DR) framework. They use a nodal network where the upper-level minimizes generation and network investment cost and the lower-level minimizes the overall payment faced by the consumers. They show how DR can contribute to adequately accommodate renewable generation in a joint expansion planning. Additionally, the potential of DR for deferring investments has been successfully demonstrated.

The first contribution of this paper is to assess the interaction between implicit and explicit demand-side flexibility. Implicit demand-side flexibility is when prosumers react to price signals triggered by electricity market prices and network tariffs. Explicit demand-side flexibility is when the DSO curtails consumers' loads for a certain amount of compensation. Two streams of literature can be identified. First, the state-of-the-art papers on network tariff design, such as Abdelmotteleb et al. (2018), Burger et al. (2020), De Villena et al. (2020), and Schittekatte and Meeus (2020), do not consider the interaction with explicit demand-side flexibility. Second, the state-of-the-art papers on explicit demand-side flexibility (also referred to as active grid management in engineering literature), such as Sarker et al. (2015), Spiliotis et al. (2016) and Asensio et al. (2017), do not consider the interaction with network tariffs. To the best of our knowledge, no prior work has been developed to analyse this relationship. In this paper, we model both to study this interaction in order to fill this gap in the literature.

The second contribution of this paper is on the level of compensation for explicit demand-side flexibility. Many studies focus on the level of compensation for supply-side flexibility but we are not aware of a similar study on demand-side flexibility. CEER (2020) highlights the importance of investigating administrative approaches for DSO’s access to flexibility, especially in case of efficiency or market failure of market based approaches.

## Methods

Our stylized model has a Stackelberg game structure. It is formulated as a Mathematical Program with Equilibrium Constraints (MPEC), using Karush–Kuhn–Tucker (KKT) optimality conditions. The model has the so-called bi-level structure. The upper level (UL) is a regulated DSO optimizes the social welfare deciding on the network investment and/or curtailing consumers as well as setting the network charge level to recover network and flexibility costs. The lower level (LL) consists of consumers, which can be prosumers or passive consumers, that maximize their own welfare. Prosumers can invest in solar PV and battery systems. They react to the network tariffs and to the compensation provided by the DSO for curtailing them. The regulated DSO anticipates the reaction of the consumers when investing in the network and when setting the level of curtailment of passive consumers and prosumers.

**Results**

We consider electricity demand data from the 2019 Belgian synthetic load profiles (SLPs). Other data for the case study are based on Schittekatte et al. (2018). First, we present the role of explicit demand-side flexibility in saving distribution network investments. We then assess its impact on system welfare in order to find the optimal demand-side flexibility level. In the full version of the paper, we further investigate the impact of network tariffs and explicit demand-side flexibility compensation. Finally, we assess the role of some context-related elements in the demand-side flexibility framework.

Figure 1: Distribution network investment savings

We find that network cost savings increase rapidly for demand flexibility volumes below 6 %, and then the curve has a less steep incline. We find that a 3% level of demand-side flexibility allows 62% of distribution grid investment savings and a 5% level allows 75%. Then, we extend our analysis to look at the system welfare for different demand-side flexibility levels. In Figure 2, we integrate the different demand-side flexibility levels in steps and then plot the system welfare levels. We find that for low levels of demand-side flexibility from 0% to 2% there is an increase in system welfare as demand-side flexibility increases. From 2% onwards, the system welfare starts to decrease. This means that the optimal demand-side flexibility level is between 1% and 3%. We then allow the model to decide on the optimal demand-side flexibility level. For the reference scenario, this results in an optimal level of 1.48% demand-side flexibility and €23,816 system welfare, normalised to the (average) consumer.

Figure 2: System welfare for different demand-side flexibility levels

## Conclusions

In this paper we highlight the potential of explicit demand-side flexibility in realizing distribution grid investments savings and increasing system welfare. Besides, we found that the interaction between implicit and explicit strongly depends on the design of network tariffs. If network tariffs are somewhat cost-reflective, the explicit demand-side flexibility results in higher welfare gains for the system. Prosumer investments in PV and batteries already consider the cost of network investments. Then, explicit demand-side flexibility is mainly used to target passive consumers that do not respond to tariffs. Furthermore, we found that it is very difficult to set an appropriate level of compensation in a context with prosumers and passive consumers. In case of a low compensation, passive consumers are only partly compensated for their loss. In case of a high compensation, prosumers may game it. Finally, we perform sensitivity analysis to assess how the different context-related parameters impact the potential of demand-side flexibility.

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