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Demand Response Potential: Available when Needed?

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ABSTRACT

The increase of intermittent electricity generation from renewable energy sources (RES) requires more flexibility from the demand side. Different applications and processes exist, which can provide Demand Response (DR) potential by shifting or shedding their load. The availability of most applications depend on the ambient temperature and/or time of day. Furthermore, their commitment is limited by technical restrictions, e.g. shifting time. In this paper, the availability and the flexibility of DR is analysed to investigate its role for the system integration of RES in Germany. In a first step, DR potential on an hourly basis is calculated for today and for future years. In a second step, the use of DR in an electricity system with different RES shares is investigated with an electricity market model. Results show, DR reduces RES curtailment. However, due to its limited availability and flexibility, it cannot integrate high amount of RES surplus over a longer period. Instead, it balances short-term fluctuation of the residual load curve. The exploited potential varies between DR applications because of their different characteristics. Therefore, focused (on selected applications) rather than broad development of DR potential is needed to shape the future energy system in a cost efficient way.

1. Introduction

1.1. Background

'Supply follows demand' used to be the main rule of the existing electricity system, to ensure security of supply at any time. Owing to the increasing share of renewable energy sources (RES), the generation portfolio in future will highly depend on weather conditions. Therefore, supply cannot be expected to follow demand at all times. High amounts of back-up, storage, and transmission capacity will be needed to ensure security of supply when no electricity from photovoltaic plants (PV) or wind turbines is available. To avoid overcapacities, it would be more efficient (from a system perspective) to adapt the electricity demand to intermittent RES supply. This requires flexible consumers and applications, which can either curtail load during times of peak demand (load shedding) or shift load to times of low demand or high RES feed-in (load shifting). These activities on the demand side are called Demand Response (DR) (Gellings, 1985; ENTSOE, 2017). Facilities and processes that can be used for load shifting or shedding are defined as DR applications.

The literature presents miscellaneous benefits of DR for the electricity system (e.g. Strbac, 2008; O'Connell et al., 2014; Nolan and O'Malley, 2015). According to O'Connell et al. (2014), DR helps to balance fluctuations caused by generation of RES. In this way, it facilitates higher penetration of renewable resources into the power system. In addition, DR can reduce load peaks and flatten the residual load. As a consequence, the need for generation capacity may decrease and power plant utilization may increase (Strbac, 2008; Gils, 2016; Qadrdan et al., 2017). For these reasons, DR could play an important role in shaping an electricity system that consists of high RES shares.

The European Commission – as well as several EU member states – has ambitious targets for future RES share in the electricity system. For instance, the German targets aim to increase RES share in the electricity system to 60% by 2035, and to 80% by 2050 (Bundesregierung, 2016). Thus, the need for flexible options such as DR is growing. Gils (2014) assessed the DR potential for Europe, which varies strongly between countries. The highest average potential for load reduction by shedding or shifting is available in Germany (13.8 GW). Therefore, this study focuses on the German electricity sector. However, this analysis could give fundamental insights for renewable integration by DR, which would also be relevant for other countries.

1.2. German Demand Response Potential in the literature

In recent years, several researchers have estimated Germany's DR potential. Stadler (2005) published the first detailed analysis. He identifies applications which are appropriate for load shifting in the industry, tertiary, and residential sectors, and focuses on the potential of non-electrical storage systems like DR. Klobasa (2007) investigates DR potential for all sectors considering miscellaneous applications. For

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Nomenclature

app	DR application (Set)
c	Country (Set)
D	Electricity demand (of an country) (Parameter)
dem^{DR}	Electricity demand of an DR application (Parameter)
dem^{Max}	Maximum demand of an DR application (equals its installed capacity) (Parameter)
DR^{DOWN}	Reduced electricity demand of an DR application (Variable)
DR^{ON}	Binary Variable which is one, when the load of an DR is decreased (Variable)
DR^{SU}	Binary Variable for starting up the load decrease (Variable)
DR^{UP}	Increased electricity demand of an DR application (Variable)
DR_SL	Virtual storage of an DR application for modelling load shifting
f	Maximum numbers of interventions per year (Parameter)
f^{d}	Maximum numbers of interventions per day (Parameter)
p	Power plant (Set)
S	Supply (generation of all power plants) (Variable)
t	Time step (set)
$t^{balance}$	Time frame within the increased and decreased demand of an DR application needs to be balanced (Parameter)
t^{freq}	Time frame between interventions (Parameter)
t^{shed}	Maximum time for reducing electricity demand of an DR application (Parameter)
t^{shift}	Maximum shifting time of an DR application (Parameter)

each DR application, he determines the maximum adjustable load. In recent years, more studies about DR potential in Germany were published (e.g. ewi, 2012; VDE, 2012; Langrock et al., 2015). The focus of and methods used in these studies differ in miscellaneous aspects. Some only focus on specific sectors or regions within Germany (e.g. Klobasa et al., 2013; Dena, 2010; Paulus and Borggrefe, 2011). For instance, Paulus and Borggrefe (2011) calculate the DR potential for selected industrial processes and Kobasa et al. (2013) identifies the DR potential for the southern part of Germany, based on surveys and open source data. Other studies consider the whole of Germany and all sectors (e.g. ewi, 2012; VDE, 2012). Owing to different assumptions and approaches, the identified DR potential for Germany varies between all studies (see Fig. 1).

The average potential in studies that consider all sectors is about 23 GW. This number seems to be quite high compared to Germany's peak load, which was 75.6 GW in 2013 (ENTSOE, 2015). This is because all studies present only the maximum potential and do not consider temporal availability in detail.[1] However, the availability of most DR applications strongly depends on the time of day, outdoor temperature, or season. D'hulst et al. (2015) present the load profile of five DR applications in the Belgian residential sector. Their results imply that the flexibility potential of DR applications varies during the day. Similar analyses were published by Soares et al. (2014) for Portugal, and Grünewald and Torriti (2013) for the UK. Thus far, no paper focuses on German DR potential on an hourly basis. However, the demand, and thus, the DR potential of most applications, depend on the outdoor temperature and/or the time of day (Gils, 2014, p.3). Therefore, it is necessary to know how much DR potential is available at what time.

Besides, DR will gain importance with the increasing share of electricity generation from RES. To analyse the contribution of DR to the system integration of RES, it is important to know the DR potential in future years. Existing studies focus on the current potential in Germany. Only VDE (2012) provides an outlook until 2030, and Gils (2015) quantifies European potential for the year 2050 in an aggregated way. Hardly any information about the German DR potential beyond 2030 can be found in the literature. Thus, it is necessary to assess the development of German DR potential in the long-term.

To summarize, current literature on DR potential in Germany neglects the temporal availability of DR applications and does not quantify DR potential in the long term. This study addresses both aspects by calculating the potential of selected DR applications on an hourly basis, and by estimating the DR potential for future years.

[1] Only VDE (2012) distinguishes between summer and winter, and for some analyses between work days, Sundays and Saturdays.

1.3. Scope and structure of this study

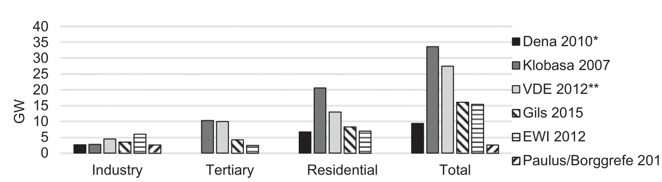
Based on the research gaps identified above, the first part of this paper focuses on the hourly availability of DR potential today and in future years, as well as on the flexibility it can provide to the electricity system. In contrast to power plants or storage systems, the overall DR potential is not available at any time and its flexibility is limited by technical restrictions such as the number and duration of interventions. Thus, its ability to balance intermittent RES feed-in may be limited as well. Therefore, the second part of this paper focuses on whether the availability and flexibility of DR fit the need, which is caused by intermittent electricity generation from RES. This is investigated with the help of a case study for Germany.

Therefore, this paper consists of two parts: first, hourly DR potential is quantified and its long-term development estimated. Section 2 presents the applied approach and assumptions. The time-dependent availability and technical restrictions of DR applications limit their flexibility. Therefore, the impact of DR on the electricity system is investigated in the second part of this paper, taking hourly DR-potentials and technical restrictions into account. The analyses are performed with the electricity market model ELTRAMOD. For this purpose, all technical characteristics that determine the dispatch of the DR applications were implemented in the model. Section 3 briefly describes this model enhancement and presents the results for different scenarios. Section 4 provides a conclusion and policy implications.

2. Calculating DR potential on an hourly basis

2.1. Variables determining the theoretical and technical DR potential

Before providing an overview of the variables determining the DR potential, the different terms are introduced and distinguished. Theoretical potential generally defines the absolute maximum potential and consists of the entire unrestricted electricity demand. In this study, this term is further limited to the hourly electricity demand of flexible applications. These are processes or applications that can shift or shed



* dena 2010 presents the positive and negative potential. The figure shows the positive one.
** VDE distinguishes between technical and theoretical potential, which is shown separately for summer and winter. The figure presents the technical potential in winter.

Fig. 1. German DR potential for the industry, tertiary and residential sector in different studies (data: Dena, 2010; Klobasa, 2007; VDE, 2012; Gils, 2015; ewi, 2012; Paulus and Borggrefe, 2011).