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# Assessment and evaluation of flexible demand in a Danish future energy scenario

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## HIGHLIGHTS

- Future potential of flexible demand is assessed through technical bottom up approach.
- Potential of flexible demand in residential, commercial and industrial is assessed.
- The system impact from the assessed flexible demand is considered through energy systems modeling.
- The necessary level of flexible demand for significant system change is assessed.

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## ABSTRACT

The aim of this article is to assess the potential of flexible demand in a far future energy system. Flexible energy systems are imperative for more integration of fluctuating renewable energy sources (RES) and therefore flexible demand as a flexible measure becomes more significant. Denmark is a leading country for high share of wind power in its electricity production and has announced to become a non-fossil fuel using country by 2050. In this article, Denmark is seen as a case due to this ambitious national goal, but the validity of the object of the analyses is not restricted to Denmark. The energy system simulated in this article is based on a Danish government year 2050 scenario based solely on RES. The article adopts two approaches for the assessment of the potential of flexible demand. The first approach is a bottom-up technical approach investigating the potential of flexible demand from individual processes. Secondly, the level of flexible demand which makes a significant impact on the future energy system is assessed with a view to investigating whether the two approaches will ever meet and thus whether flexible demand has a significant role to play in the future energy system. The results show that the potential of flexible demand is only found in the 2 h time frame with 24% and the daily time frame with approx. 7% of the electricity demand. The system benefit at the assessed amount of flexible demand is limited however. Results from the other analysis indicate that in order to have a significant impact on the energy system performance, more than a quarter of the classic electricity demand would need to be flexible within a month, which is highly unlikely to happen. The value of flexible demand in the energy system is thus limited.



## 1. Introduction

In order to reduce greenhouse gas (GHG) emissions [1,2], the exploitation of RES is getting increasing attention as alternatives for fossil fuel resources. For the integration of RES, however, it is essential to make the energy system flexible to accommodate the fluctuations in production and RES-based energy systems require significantly more flexibility than fossil fuel-based energy systems. In a fossil fuel-based electricity system, the flexibility is mainly evaluated by how well the system deals with the outage of fossil fuel power plants through N-1 or N-2 criteria whereas the system's load-following capability is hardly an issue. The outage of fossil fuel power plants is much less prevalent than imbalances attributed to the intermittency of RES in high-RES electricity systems either from forecast errors or from correctly forecasted occurrences that the electricity system has difficulty of handling. Therefore the flexibility of electricity systems, which are highly integrated with intermittent RES, is a more important issue than in electricity systems based on fossil fuel power plants [3–6]. In electricity systems, the flexibility on the supply side is regarded as an important condition as more intermittent renewable energy resources are integrated into the electric grid.

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Until now, most of practical endeavors to cope with fluctuating RES have focused on the supply side of the electric system whereas not much has been implemented on the demand side.

For the purpose of balancing supply and demand in the electric grid, demand flexibility can provide the exact same service as the supply side as long as the same extent of controllability on both sides is assumed. Hence demand side flexibility is getting more attention as ICT (Information and Communication Technology), which enables consumers to monitor and control their demand automatically, develops. With this technology, electricity demand may react to real-time price signals [7] and real time energy system requirements.

A large body of literature already exists in which the research subject is flexible demand as a means for providing flexibility in the energy system with the objective of integrating RES. Several research efforts investigate the flexibility of the residential demand. Dupont et al. [8] investigate the impacts of residential demand responses such as white goods and battery electric vehicles (BEV) within the present (2012) and future (2025) Belgian context. The results show that the demand response could make an impact mostly on mid-peak and peak generation units. Also, the impact of BEV is larger than that of the aggregation of white goods such as washing machine, dryer, and dishwasher. Broeer et al. [9] investigate the relation between wind power and demand response. The demand response is limited within thermal residential demands like heating, ventilation, and air-conditioning. Bartusch and Alvehag [10] investigate the potential of demand response with empirical data among Swedish single-family homes and apartment residence. They conclude that the consumers respond to price signals resulting in a reduction of the peak demand and a shift it to less demanding hours. For the assessment of flexibility from industrial demands, Finn and Fitzpatrick [11] exemplify two industrial consumers to assess the potential of demand side management. Both industrial consumers increase electricity consumption during high wind period when they are subject to real time whole-sale electricity prices. For the simulation of flexible demand, linear optimization [8,11] and stochastic programming [12] are used. Conejo et al. [13] introduce an optimization model to find the consumption pattern under uncertain electricity price situations. The uncertainty of price is simulated through robust optimization. Furthermore Ferreira et al. [14] analyze the role of price correlation in successive periods for better simulation of real world using robust optimization methodology.

This study has several discerning points from the past research. Existing analyses on flexible demand related to the integration of RES has only been carried out to a limited extent – and with a limited scope. Some analyses focus on specific technologies or processes such as dishwashers [15], and refrigerator [16]; other analyses target a specific energy sector i.e. residential sector [8,17] or industrial sector [11,18,19]. Stadler [20] investigates flexible demand only from thermal related electricity demand which include using a combination of thermal storage and electric heat pump. Similarly, the impact of BEV is investigated as flexible demand [8,21,22]. None of the studies identified in a literature review address the entire energy sector which is thus a discerning factor for this study.

Investigating the flexibility of classic electricity demand is another discerning factor for this study.

The reviewed analyses observe the flexibility of demand only [9,15,23,24], but not within the context of a future coherent energy system considering various kinds of flexible technologies and storage facilities simultaneously. Using a future context and combining assessments of flexible demand with holistic energy systems analyses is thus a third distinguished point for this study.

In the future the significance of flexible demand is different from that of the present time since there are other flexible measures to buffer the intermittency of RES in exiting fuel-based energy systems. Thus, a future context is necessary. For the assessment of flexible demand in a future context, a Danish 100% RES scenario is used.

Denmark has an ambition of becoming independent of fossil fuels by 2050, and to this end, the Danish Government established a Climate Commission to demonstrate possible pathways. The Climate Commission suggested four scenarios according to two assumptions of international framework and limitation of biomass consumption [25]. Among the scenarios, the recommended 2050 scenario which assumes ambitious international framework and limited biomass consumption (referred to as CC2050 henceforth) is selected for this research. In the CC2050, the Climate Commission lists flexible demand as a necessary component in the future Danish energy system without, however, quantifying the potential available amounts nor the required amounts of flexibility in a 100% RES-based energy system [26,27].

In this article, the potential and system benefit of flexible demand in the far future is assessed from two approaches. In the first approach, which is a bottom up, the potential future flexible demand is assessed in the residential, commercial and industrial sectors in the context of a year 2050 100% RES scenario. Subsequently, this scenario is simulated using and modifying the energy systems analysis model EnergyPLAN (see Section 4) in order to assess the system benefit of the potential flexible demands established. In the second approach, which starts from the systems level, the required system effects are first defined and then it is analyzed which level of flexible demand is adequate to realize these system effects.

This article proceeds as follows. For the state of the art and methods discussion, Section 2 represents the two branches of methods to analyze the flexible demand potential and discuss which method will be used in this article. Section 3 assesses the potential of flexible demand in the residential, commercial, and industrial sectors based on the present Danish electricity demand. Section 4 describes EnergyPLAN and the modifications of the EnergyPLAN model to fit the purpose of the study. Section 5 establishes three scenarios on flexible demand. Finally, results and conclusion follow in Sections 6 and 7.

## 2. Methods for assessing flexible demand

### 2.1. Aggregated and decomposition methods

There have been a number of studies to assess the potential and value of flexible demand with different methodologies. The methodologies can broadly be categorized into two by whether the electricity demand is viewed at an aggregate level or individual level divided into specific electric services.

The aggregated approach relies on market mechanisms for assessing the demand change in accordance to electricity price change. For that, price elasticity is necessary for assessing the change as well as market data to present the normal price variation in the system. Both data sets can be empirical like market data, or particularly for the case of price elasticity it would be assumed numbers as short term empirical data, such as real-time elasticities, are rarely found [28]. Several studies use this approach to assess the potential and financial value of flexible demand. Zarnikau et al. [29] assess the aggregated industrial demand response to price change, based on a market-based analysis. The results confirm that the responsiveness of industrial loads is very small to wholesale electricity price levels and that there are factors contributing to the low responsiveness, including types of demand response service, and short notice period for price change. Sezgen et al. [30] estimate the value of demand response technologies