Comparing energy systems in California and Sweden: A pilot-study to further develop a methodology for prediction of overall demand response potential in Northern Europe

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Abstract

The share of electricity generation from renewable resources (e.g. wind and solar) is increasing, as a consequence of environmental targets, to avoid the imminent risks of climate change. Renewable generation is less predictable and controllable than conventional generation, which introduces new challenges for the energy system as a whole. Consequently, demand side management is gaining increased attention for its conceivable potential of providing needed operational flexibility to the energy system. However, little is still known about the size, accessibility and cost of using demand side flexibility on a broader scale. To attain better knowledge, this paper proposes a conceptual framework for how a forecasting tool, previously developed for California, could be adapted in a Swedish demand response potential study. This tool would enable prediction of the demand response potential on a system wide scale. The tool can then be used by researchers and policy makers in order to understand the size of the resource, prioritize research needs and to support policymaking.

Introduction

The activities through which the activation of the demand side is attempted are commonly referred to as demand side management (Paterakis, Erdinç et al. 2017). Demand side management includes demand response (flexibility), demand management (efficiency/reduction), and distributed generation (Drysdale, Wu et al. 2015). Federal Energy Regulatory Commission (FERC) gives the following definition to demand response: *"Changes in electricity usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized"* (ferc.gov). General motives for demand response are management of peak capacity, improved affordability of electricity, improved grid reliability and enablement of more renewables on the grid. It may serve as an important resource for keeping the electricity grid stable and efficient; deferring upgrades to generation, transmission, and distribution system, and can also provide societal economic benefits.

OBJECTIVES WITH THIS STUDY

The objectives of this paper are to

- provide an overview of available methods to estimate demand flexibility potential on a large level such as a nation or a state
- compare the electricity generation and energy markets between California and Sweden and discuss their implications on demand response needs and barriers
- provide an understanding on how existing methodologies can be implemented in Sweden and elsewhere

OUTLINE OF THE PAPER

The paper is organized as follows. First, previous studies on demand flexibility are presented and their methods are discussed. Next, a general background description for the motives for demand response in California is provided, which gives a foundation to understand later discussions in the paper. Then, a comparison of energy supply systems and the energy markets in California and Sweden are provided; and the main motives for implementing demand flexibility in each region are discussed. Finally, some conclusion and outlook for future holistic demand studies in Sweden are provided.

Previous studies

Paterakis, Erdinç et al. (2017) provides an extensive up-to-date literature overview on demand response worldwide. It presents an analysis of demand response programs and consumer response types. It also provides a description of the benefits and the drivers that have motivated the adoption of demand response programs, as well as barriers that may hinder their further development. Furthermore, they identify the international status quo by reviewing existing demand response programs in different regions. According to Paterakis, Erdinç et al. (2017) the North American market is the global leader in terms of development and deployment of demand response programs. In the U.S., many utilities are already legally obligated to consider demand response in their resource planning (Satchwell and Hledik 2014). Paterakis, Erdinç et al. (2017) point out that the EU countries are showing an expanding interest for future demand response. Torriti, Hassan et al. (2010) has examined the advance of demand response within the European countries. While the potential for demand response varies across Europe, they argue that there are common reasons as to why demand response policies have been slow to emerge. The reasons they bring up are limited knowledge on demand response capacity for energy savings; high cost for technologies and infrastructures; and policies having mainly focused on market liberalization. Furthermore, Torriti, Hassan et al. (2010) makes four observations when reviewing European case studies on demand response potential. 1) The total amount of demand response, as analyzed in system adequacy studies, is rather low and flat, 2) load management forecasts increased during recent years, 3) most existing demand response initiatives consists of interruptible programs, and 4) a significant number of European countries do not even consider demand response in system and network planning. Another reason why EU has not really got involved in demand response policies is that it did not use to have an adequate system in place to monitor the market. However, with EU's Third Legislative Package for the Internal Energy Market in 2009, the European Network for Transmission System Operators for Electricity (ENTSO-E) was established (entsoe.eu). ENTSO-E represents 42 electricity transmission system operators (TSOs) from 35 countries across Europe. The objectives of ENTSO-E are to set up the internal energy market and ensure its optimal functioning. ENTSO-E identifies demand response as a key component in a successful evolution of the power system from a conventional based generation system to one that has significant intermittent resources for generation. According to a policy paper by ENTSO-E, demand response must be broad and deep in order to achieve the EU's 2030 and 2050 energy policy and CO_2 targets (entsoe 2014). Another aspect brought up by Torriti, Hassan et al. (2010) which will enhance the possibility for demand response in Europe is the wide roll-out of smart metering technology. Also, the European Energy Efficiency Directive (EED) (eur-lex.europa.eu) includes considerations for demand response. It states that *"transmission system operators and distribution system operators, in meeting requirements for balancing and ancillary services, treat demand response providers, including aggregators, in a non-discriminatory manner, based on their technical capabilities"*. It also states that *"Network or retail tariffs may support dynamic pricing for demand response measures by final customers, such as: (a) time-of-use tariffs; (b) critical peak pricing; (c) real time pricing; and (d) peak time rebates.*

ESTIMATED DEMAND RESPONSE POTENTIAL IN CALIFORNIA AND SWEDEN

In California, according to Alstone, Potter et al. (2017) the investor owned utilities currently provide about 2.1 GW of demand response. The results from the study's forecast show for example, that a conventional shed of 4.2 GW can be provided in 2025. Furthermore, there is an additional potential of 1 GW if "time of use" and "critical peak pricing" is included, giving a total shed potential of 5.2 GW. See report for the full set of scenario assumptions and results for all service types for different sectors, subsectors and end uses (Alstone, Potter et al. 2017).

In Sweden, the Swedish Energy Markets Inspectorate [Energimarknadsinpektionen] (Ei) recently published a report, in which they investigate the conditions and barriers for different customers to increase economic efficiency in the electricity market through increased demand flexibility (Ei 2016:15). In the report Ei (2016:15) presents their estimated current potential of demand flexibility in Sweden, based on a few previous studies (Cronholm, Forsberg et al. 2006, NEPP 2016, Nyholm, Puranik et al. 2016). According to Ei (2016:15) the potential for demand flexibility is largest among residential and industrial electricity customers. Among the residential customers it is above all the single family houses with electric heating that can provide flexibility, which makes the potential dependent on the season. In the work by Nyholm, Puranik et al. (2016) the potential in single family houses is modelled based on an economic optimization, so it only reflect demand flexibility potential that are economically favorable in terms of lowering electricity cost for the customer. The model is based on 571 sample buildings with electrical heating and the results are extrapolated to represent the building stock of Sweden by means of weighting coefficients that are related to the frequency of each representative building in the building stock investigated. It should be noted that Nyholm, Puranik et al. (2016) points out that with current price structure there is only a weak economic incentive for demand flexibility from the house owners' perspective. The results show an average saving of 2.0–3.7 % on the annual bill for electric heating.

METHODS TO ESTIMATE DEMAND RESPONSE POTENTIAL

Lawrence Berkeley National Laboratory (LBNL) has developed a model for forecasting the technical and economic potential for demand response in the state of California (Alstone, Potter et al. 2016b, a, 2017). The model was recently publicly released as an open source beta version, intended for other scientists to use. The model is developed in the programming language Python (Alstone, Potter et al. 2016a). The LBNL model can be seen as a top-down model. The study includes the three largest investor owned utilities in California. It examines load data from ~11 million customers and groups them into clusters based on similarity of their demographic and load. Then, hourly smart meter data from ~220,000 customers are examined to define characteristic load profiles for the clusters, as total load and by end uses. Based on this, loads are forecasted for year 2020 and 2025. The study includes industry, residential, commercial and agriculture. Development of a demand response forecasting tool based on such large amount of smart meter data is a novel approach which has not been found in any other study. It enabled a total new way of analyzing and quantifying possible values and benefits of demand response beyond current market practices.

There are four conceptual service types defined in the study, with the purpose of bringing a more nuanced description of different types of demand response; 1) shape, 2) shift, 3) shed and 4) shimmy. Shape captures demand response that reshapes the underlying load profile through relatively long-run price response of behavioral campaigns. Shift represents demand response that encourages the movement of energy use from times of high demand to times of day when there is surplus of renewable generation. Shed describes loads that can occasionally be curtailed to provide peak capacity and support the system in emergency of contingency events. Shimmy involves using loads to dynamically adjust demand on the system to alleviate short-run ramps and disturbances at timescales ranging from seconds up to an hour.

There are other studies that use a bottom-up approach instead (e.g.Nyholm, Puranik et al. 2016, Sandels 2016). Bottom-up simulation model can in more detail capture processes on a load-level. As opposed to top-down models, bottom-up models start from the lowest level of components (e.g., an appliance). Sandels (2016) has developed models to simulated demand response in office buildings and detached residential houses and Nyholm, Puranik et al. (2016) have developed a model for single family houses. The results of such models are of importance for development and assumptions made when analyzing the energy system as a whole, as is the aim in top-down models.

GAP IDENTIFICATION – THE MISSING HOLISTIC OVERVIEW IN EUROPEAN MARKETS

Several studies focus on the end-use and how its particular potential can provide a flexibility. They do not neccesary take into account how efficient each option are to provide a solution for the challenges of the supply system as a whole. Nore does it give comparisons to other options that could provide an equivalent flexibility service output. It would also be of interest to compare cost effectivness of different flexibility services and moreover put it in relation to traditional investments in grid and generation. Never the less, these bottom-up studies and the knowledge they bring are important and useful to understand the flexibility from the demand side's point of view. A natural next step is to combine the results from these individual studies, to provide an overview and map how these different options of end-use flexibily can be integrated into an optimized supply and demand system. Such, holisitic overview studies, where the supply and demand are analysed based on an optimal integration, are stil lacking today. The first study that has created a model for such integrated analysis is the California potential study (Alstone, Potter et al. 2016a, b, Florio 2016, Alstone, Potter et al. 2017). It should be noted that this model includes a large amount of input data, as well as sientific assumptions that do introduce uncertainties in the model output. However, it still provides a tool that can be improved upon. It gives a valuble representation of the world that increases our ability to analys and understand how different policies and technologies can affect the system.

Motives for demand response programs in California

Today, the main motivation for demand flexibility in California are management of peak capacity during hot summer days, improved affordability of electricity, improved grid reliability and enablement of more renewables on the grid (Piette 2016). Historically, demand flexibility was primarily used in California to manage peak demand, largely due to air-conditioning during hot summer days. However, according to Alstone, Potter et al. (2017), this type of demand response will be of less importance in the future. With increasing renewable generation, the grid will face other challenges. Management of renewable integration will call for demand response that can compensate for the uncontrollability of this new generation. The greatest need is to shift load to consume more energy in mid-day, and less in early evening.

The system operator is responsible for balancing variability in electricity demand, but also for balancing variability in intermittent wind and solar generation. Therefore, the electricity supply must be balanced against an increasingly less predictable "net load", i.e., the load after subtracting the output of intermittent wind and solar resources. This subtracted intermittent generation includes both costumer site rooftop photovoltaics as well as utility-scale renewables (California ISO 2013). The system operator CAISO created the "duck curve" to show the impact of grid-connected photovoltaics systems on the electric grid's operation (Obi and Bass 2016). Figure 1 shows this net load, the "duck curve", on a spring day for different years. It shows how the transition to more renewables changes the net load curve (California ISO 2013). The net load is calculated by taking the forecasted load and subtracting the forecasted electricity production from wind and solar. These curves capture the total variability that the system operator must match or follow with other dispatchable and controllable resources. Between each year more solar are added to the system, which causes the decrease in net load during daytime. Among California stakeholders this figure is famously referred to as the "duck-curve". You can imagine the tail of a duck to the left and the duck's belly being the mid-day drop due to installment of more solar generation. The ramp in the afternoon is the duck's neck and the evening peak the top of its head. The increased ramp from the "belly" to the "neck" is caused both by solar disappearing during sunset as well as an increased demand for electricity in the evening. Solar fades just in time for people to come home from work. As can be seen the characteristic of the net load profile is changing dramatically as renewable generation is increased, creating new challenges for the system. The figure shows actual data from 2012 and 2013, and predictions for 2014 to 2020. In 2016, it turns out that the changes in load-supply balance are coming even faster and deeper than expected (greentechmedia.com 2016). Furthermore, greentechmedia.com (2016) argues that the change is driven more by utility-scales solar than by costumer site rooftop photovoltaics.

Figure 2 shows the predicted gross load generation by source in 2020. It also includes renewable generation, total end use, load demand and over-generation. Alstone, Potter et al. (2016b) points out a number of challenges that are illustrated in Figure 2:

1. Downward ramping: To make room for significant influx of solar energy after sun rises, downward ramping and potential shut down of night time thermal power plants will be needed.

2. Minimum generation: With high renewable production, particularly solar, over-generation may occur creating a need for more flexibility to reduce generation from thermal power plants.
3. Upward ramping. Shortly after sunset, thermal power plants must ramp up quickly and new units may be required to start up to meet the evening peak demand. This requirement of quick ramping increases generation costs.
4. Peaking capacity: Despite the lower resource requirement mid-day there still need to be enough resource capacity to meet the highest peak with sufficient reliability.

Electricity generation and load in California and Sweden

Demand response is not a purpose of its own. The main reason why demand response is gaining attention is its ability to provide value and benefit to the power system as a whole. California is one of the leading markets when it comes to implementation of demand response programs. Therefore, when creating demand response programs for other markets, the experience and knowledge from existing mature markets should be taken into account. However it is important to understand and acknowledge that there are different preconditions that affect which qualities of flexibility services that would benefit the system. Therefore, we start the comparison between California and Sweden by looking at the electricity generation and loads.

One of the most important characteristics that distinguish the different resources is if the generation can be planned, or if the electricity only can be produced during certain weather conditions. This in turn determines whether the resource can deliver electric power when needed. Another important aspect is weather the resource can go with variable output and thus can be used as regulating power (Byman 2015).

Figure 3 shows the mix of electricity generation in California and Sweden, not including import and export. In California 60 % of the electricity generation is provided by means of natural gas. Other sources are nuclear, hydro, geothermal, wind and solar (data from energy.ca.gov). In 2015, utility-scale solar photovoltaic and solar thermal resources supplied 7.5 % of the net generation (eia.gov). The amount of hydroelectricity produced varies each year, and is largely dependent on rainfall. As an example, in 2013 hydro accounted for 12 % of the in-state electricity generation and in 2014 it was down to 6 % (energy.ca.gov).

In Sweden, hydro and nuclear are the dominating sources of electricity generation, accounting for 84 % of the total mix. Remaining generation consists of mostly wind. Other generation consists of cogeneration and thermal power plants. According to SOU 2017:2 (2017), wind has increased significantly in recent.

For Sweden, hydro is an important balancing resource at all timescales, from seconds to seasonal balancing. In the work by Brandsma, Odenberg et al. (2016) historical data was used to quantify the characteristics of the past balancing contribution from hydro power plants. Data were gathered for year 2007–2014. The analysis is based on approximately 400 of the largest hydro power plants, with regards to maximum capacity. In total there are about 2 000 hydro power plants, with a total capacity of approximately 16 000 MW. The analysis is an evaluation of the

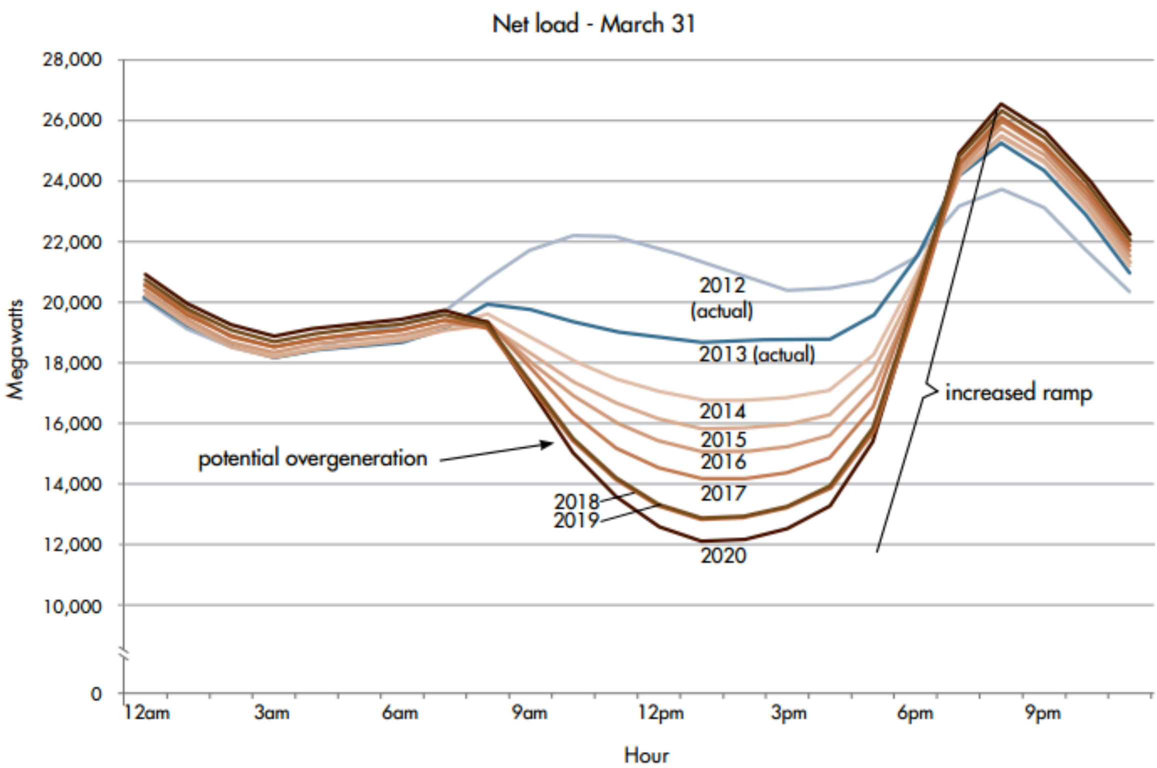


Figure 1. Net load forecast, simulating a spring day in year 2014-2020. This so called "duck-curve" shows how the California net load is changing with increased renewable generation. The net load is the actual electricity demand on the system minus variable generation from both costumer site and utilities. (California ISO 2013).

past balancing situation. Future scenarios, that include forecasts of increased balancing needs, were not performed. They conclude that 255 hydro power plants constitute the major part of the provided balancing service to the system. They further argue that increased balancing from hydro is the most likely solution, known today, to solve future expected increase in balancing needs. Meanwhile, they also point out that, there are no incentives in place today to increase the balancing capacity within existing resources or to introduce new balancing resources.

RENEWABLE AND EMISSION TARGETS

We will briefly discuss the targets for renewable energy and CO_2 emission reductions in California and Sweden, since these targets will affect the evolution in future electricity generation.

California has one of the most ambitious renewable energy targets in the U.S. (cpuc.ca.gov). The California renewable portfolio standard (RPS) requires utilities to procure 50 % of their electricity from renewable generation by 2030 (energy.ca.gov). With regards to hydro, utilities are only allowed to include hydropower with a maximum capacity of 30 MW in the RPS count, which is a common criterion also in other states' RPSs. In addition, California has supplementary environmental criteria which even further limit the inclusion of hydropower (Stori 2013). The California emission reduction target is 40 % below 1990 levels by 2030 (Florio 2016).

In Sweden all hydro is counted as renewable towards energy targets. The current Swedish renewable energy target for year 2020 is that the renewable share of the total energy use should be at least 50 % (regeringen.se). However there has been a recent political debate about future targets. In June 2016 the Swedish government coalition (Socialdemokraterna and Miljöpartiet) together with a couple of the opposition parties (Moderaterna, Centerpartiet and Kristdemokraterna) presented a broad agreement for the Swedish energy policy, where they commit to the ambitious target of 100 % renewable electricity generation by year 2040 (government.se 2016, SOU 2017:2 2017). This agreement constitutes a joint roadmap for the parties involved. However according to the agreement nuclear is not prohibited. Note that allowing nuclear power plants while having a goal of 100 % renewables is inconsistent and contradictory.

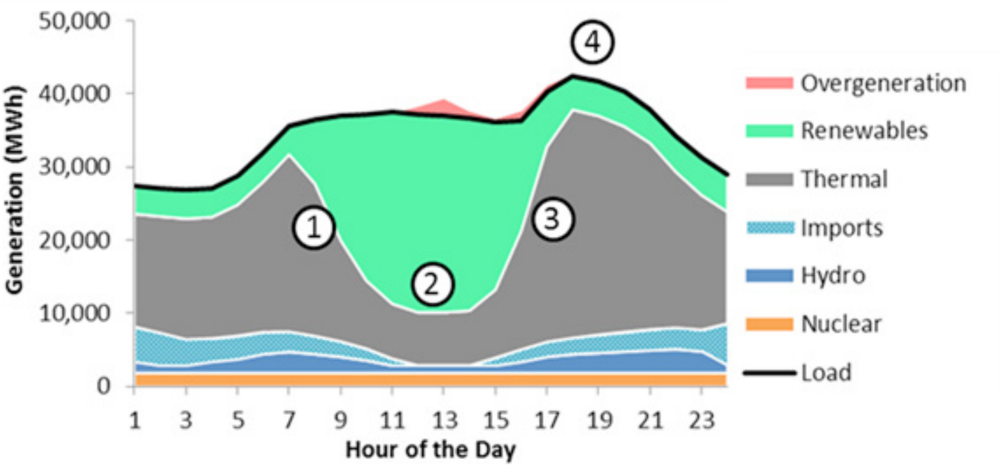
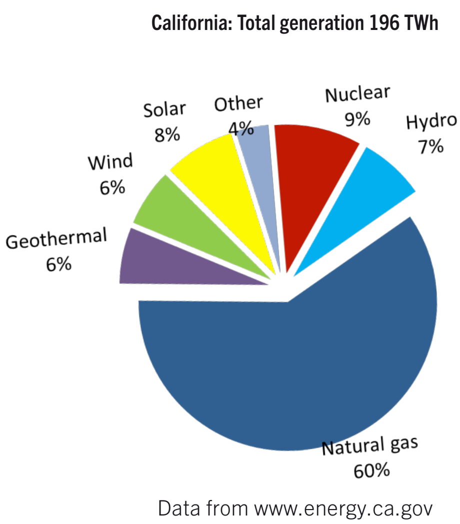


Figure 2. Predicted gross load generation by source in 2020. Illustration copied from Alstone, Potter et al. (2016b).



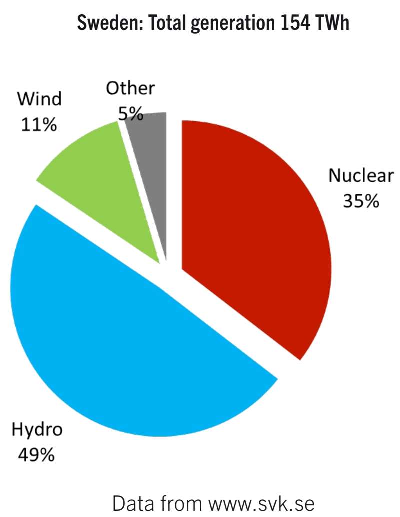


Figure 3. Comparison of total in-state/in-country electricity generation in California and Sweden in year 2015, excluding import and export.

GENERATION PROFILES

Figure 4 and Figure 5 show electricity generation for California and Sweden, respectively. The hourly values are shown to the left in the figures. To the right, a set of 24 hours for each month are shown. These daily profiles are the average output for each hour in a given month. In California, Figure 4, it can be seen that there is a high evening peak throughout the whole year. Through large parts of the year there is also a significant morning peak. This means that the bas power system has to adjust its supply for these two peaks throughout the day, it has to ramp up and ramp down for. For thermal power plants this might not be as cost effective as if the plant was to run on a more constant level of output. In Sweden, Figure 5, it can be seen that all ramping is provided by means of hydro power, a resource which is considered to easily and cost effectively provide flexibility. Sweden has relatively more wind generation than California. The wind generation is highly fluctuating, this fast changes in electricity generation might create considerable challenges for the balancing authorities in Sweden.

DURATION LOAD CURVE COMPARISON BETWEEN CALIFORNIA AND SWEDEN

Figure 6 shows the duration load curves for California and Sweden in year 2015. The California peak load was 47 GW and occurred on the 28th of August. The Swedish peak load was 25 GW and occurred on the 27th of February. As can be seen Sweden does not have as "peaky" and high peak demand as California does. It was the peak demand that historically made California develop its demand response market. Since the highest peak only occurs during a few hours it makes sense to work on demand side solutions. These peak hours otherwise requires expensive generation. If supply cannot meet the demand there is a risk for power outages. The Swedish, "flatter", load curve might indicate a lesser need for traditional shed type of demand response services. However, the Swedish government (regeringen.se) points out that when nuclear power is being shut down, we will see an increased challenge regarding capacity during the coldest winter days in southern Sweden.

Electricity markets

If and how different demand flexibility technologies, in reality, can be enabled is highly dependent on the market situation. California and Sweden have significantly different market structures. The actors within the electricity value chain have to manage their operation with regards to the industry structure at play. Figure 7 presents four common industry structure models, A) vertical integrated, B) single buyer, C) wholesales competition, and D) retail and wholesale competition. In the U.S., models based on integrated utility structures prevail, which are shown as model A-C in Figure 7. In the case of California it is, model C, wholesale competition which applies. In Europe, on the other hand, model D, both retail and wholesale competition applies. This is a result of the European Commission's laws regarding functional and legal unbundling of network operators. The unbundling refers to a split between network operations from supply or production activities in order to allow non-discriminatory grid access to all market parties.

The two major activities related to the transmission network are ownership and system operation. Ownership is associated with investment and building of infrastructure. System operation is associated with central control to ensure security, economy and reliability of the power system. In most European countries, a single company that is termed the 'transmission system operator' (TSO) is responsible for both the ownership and the system operation. Generally TSOs must be independent from the generation companies. Whereas, in most U.S. states, the operation of the system is assigned to an entity that is independent from both the transmission and generation owners, termed 'independent system operators' (ISO). ISOs manage a grid that it does not own, since the U.S. transmission grid is privately owned and fragmented. The Swedish TSO is Svenska Kraftnät (Svk) and the California ISO is abbreviated and referred to as CAISO.

ELECTRICITY MARKET IN CALIFORNIA

CAISO is the balancing authority with the responsibility for 1) operating the wholesale market and 2) for managing the reliability of the transmission grid. In managing the grid, CAISO centrally dispatches generation and coordinates the movement

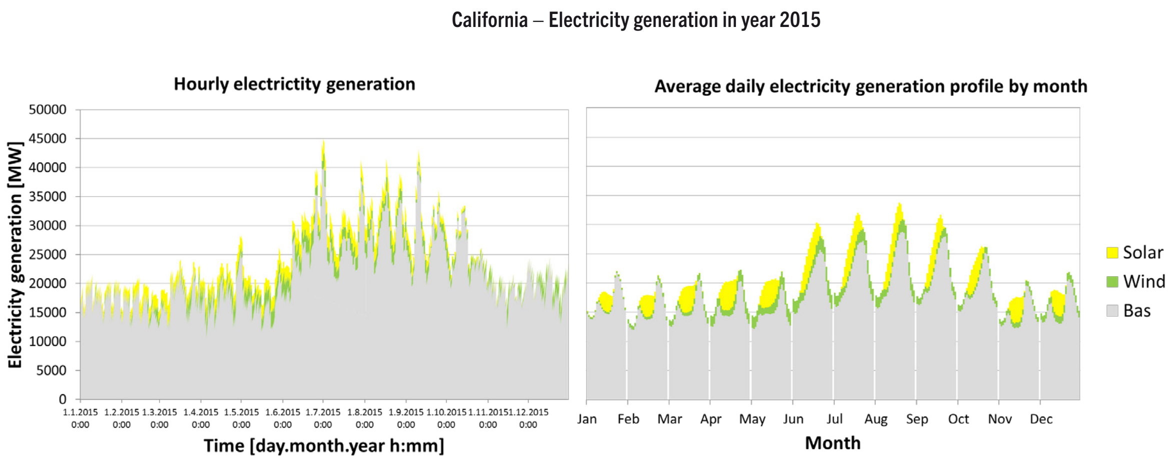


Figure 4. California electricity generation by source in 2015. Hourly values to the left and daily average profiles by month to the right. Data from CAISO retrieved through the Pyhton library Pyiso (Pyiso 2016). Note: Separate hourly values were only available for solar and wind, all other generation are gathered under 'bas'.

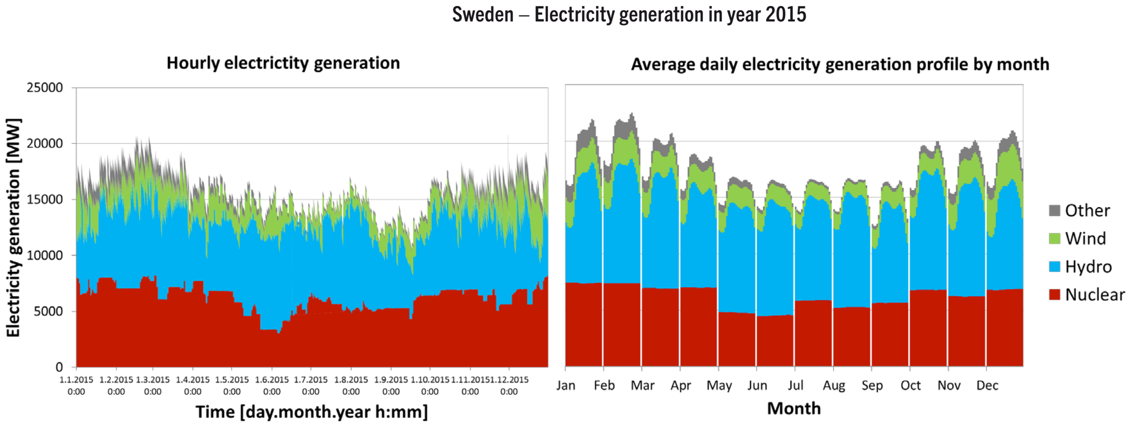


Figure 5. Swedish electricity generation by source in 2015. Hourly value to the left and daily average profiles by month to the right. Data from www.svk.se.

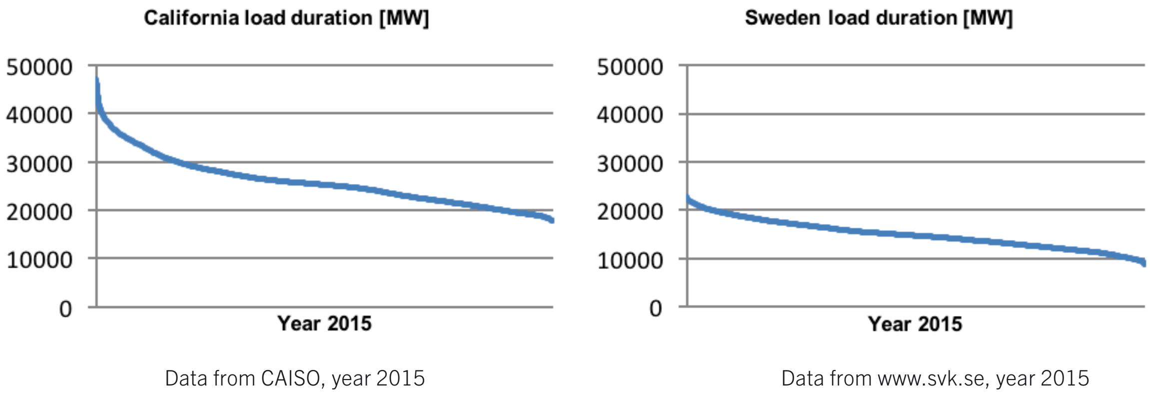


Figure 6. Load duration curves for California and Sweden.

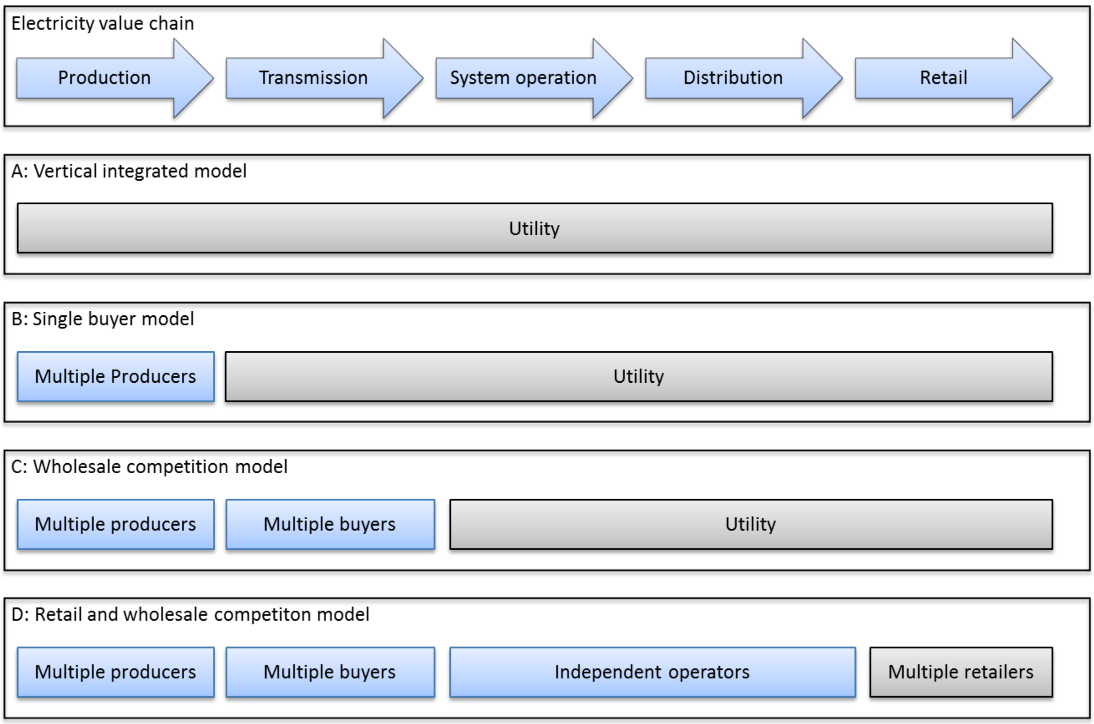


Figure 7. Common industry structures within the electricity value chain. Illustration is adapted by the author from Eid, Hakvoort et al. (2016) and Batlle and Ocaña (2013).

of the wholesale electricity. The electricity system is California is currently a mix of regulated and deregulated (Cook 2013). In the wholesale market, utilities purchase power primarily from independent electricity producers at a competitive wholesale price that is set using an auction process administrated by CAISO. CAISOs markets include day-ahead market, real-time market, ancillary services and congestion revenue rights. CAISO also operates an Energy Imbalance Market (EIM). The day-ahead market opens seven days in advance of the targeted trading day and closes at 10:00 on the day before the energy will be used. The real-time market opens when the day-ahead process is complete and it closes 65 minutes ahead of each operating hour. In the retail market, electricity utilities sell power to end-use consumers at prices that are regulated by the California Public Utilities Commission.

ELECTRICITY MARKET IN SWEDEN

Customers in Sweden are able to choose their power supplier, this because the electricity market was deregulated and unbundled in 1996. Since then electricity is traded on the competitive market Nord Pool. Distribution of electricity is still a monopoly. In Sweden it is Svk who is the transmission system operator. Svk is responsible for maintaining the balance between electricity generation and use of electricity and they are also a partial owner of Nord Pool. The electricity market in Sweden is directly linked to the electricity markets in Denmark, Norway, Finland, Germany, Poland and Lithuania, and indirectly it is linked to almost all of Europe. The electricity market is now divided between four segments; 1) future contracts 2) the day-ahead market, 3) the intraday market and 4) the regulating power market (capacity market). Long term future contracts are traded on Nasdaq and the timescale for these contracts range between days to years. Nord Pool manages the day-ahead market (also known as Elspot) and the intraday market (also known as Elbas). On the day-ahead market contracts are made between seller and buyer for the delivery of power the following day. The day-ahead market closes at 12:00 the day before delivery. The majority of the trade on Nord Pool is handled within the day-ahead market, and for most part the balance between supply and demand is secured here. However, incidents may take place between closing of the day-ahead market and delivery the next day (i.e. unplanned interruption of a power plant or strong winds resulting in high power generation from wind turbines). The intraday market supplements the day-ahead market and helps secure the necessary balance between supply and demand in the power market. Here buyers and sellers can trade volumes close to real time to bring the market back in balance. The required amounts of regulation and reserves are allocated to each member country by Nord Pool. This arrangement ensures that each country contributes its fair share to maintain the reliability of the grid. It is the electricity suppliers who have the balancing responsibility. The balance is controlled both automatically and manually within the hour of operation. Of the balancing resources used in Sweden almost 100 % is provided by means of hydro power and it is therefore crucial for maintaining the system balance.

EUROPEAN UNBUNDLED MARKETS AND CONSEQUENCES FOR DEMAND FLEXIBILITY POTENTIAL

In Europe, the liberalized environment has enabled several new entities in the electricity markets that have different roles, responsibilities and objectives. However, according to Paterakis, Erdinç et al. (2017), this situation may impose barriers towards the uptake of demand response, especially because of the contrasting views and the absence of an aligned position as regards the use of flexibility between TSOs and distribution system operators (DSOs). The majority of demand flexibility resources are connected in the distribution system and as a result, the collaboration between TSOs and DSOs is important in order to exploit demand response. However, issues regarding the purpose of demand response deployment may complicate the development of demand response programs. For instance, TSOs would view the flexibility provided by demand response as a means of balancing the system, while DSOs would use it in order to mitigate local congestions. This implies that coordination between these entities should be developed in order to design different demand response products that would transparently and legally allow the utilization of demand response in the system and market operations. Furthermore, Torriti, Hassan et al. (2010) points out that the move away from integrated planning via state-run institutions towards private sector decision making and investment seems to have favored more traditional supply side investments as the route to keep pace with economic growth and rising electricity service demands, rather than investigations and investments on demand side solutions.

EUROPEAN IMPLICATIONS OF AN ENERGY-ONLY MARKET

Svk (2016) argues that the energy-only market that applies today does not incentivize secured capacity. It puts a price on energy but it lacks any mechanisms to handle the system need for capacity and flexibility. During certain weather conditions this leads to a low electricity price, consequently outcompeting generation that can be planned (i.e. the weather independent generation). It is only the weather independent generation that can provide sufficient security of capacity. Without subsidies or incentive, investment in new weather independent generation will not happen. Consequently, the possibility of introducing regulation of capacity is discussed in several countries within Europe. This however could create another problem. If separate countries introduce independent capacity regulation this could distort the competition and reduce the market's effectiveness. Furthermore, Svk (2016) argues that if the Swedish nuclear is going to be phased out, it would need to be replaced with other weather independent generation; however there are no incentives yet that will make that happen. Elforsk Market Design (2014) discuss that on an energy-only market such as Nord Pool there are normally no incentives to limit the energy use during peak demand hours. This is because the underlying electricity spot price only has a marginal effect on the retail price for the end customer. Since no one is paying for capacity there is a risk that supply cannot meet demand. To solve this problem, more capacity can be built into the system with more regulating power (this is expensive) or agreements can be made with the customers to abstain electricity use when demand is high.

SECURITY OF CAPACITY IN SWEDEN

The power market in Sweden is built on the idea that the market itself should ensure adequate availability of capacity to meet demand. It is the price signal on the different markets that signals lack of capacity and the market should thereby adjust to ensure sufficient capacity to meet customers' demand. There are however governmental policies to handle reliability issues when it comes to the distribution of electricity. For 20 years there have not been any incentives or regulations for the producers to invest in new conventional and controllable capacity. Instead producers have made any investments based on predicted profitability. According to Svk (2016) this has worked well, also overinvestments in production have disappeared. On the other hand Svk (2016) also mentions that producers have had to shut down production units, on commercial basis, because of low electricity prices. Power plants that are of importance for the security of capacity have not been profitable in the current market structure. SOU 2017:2 (2017) points out that the announced, possible, closure of four nuclear power reactors and the expansion of variable electricity production have contributed to an increased focus on the significance of capacity.

Discussion

For the purpose of this paper, the discussion centers on a comparison of the elecricity generation and energy markets in California and Sweden. There are different motives and barriars for implementation of demand response in these regions. California was chosen because that's where a recent large scale and in depth demand response potential study has been performed which includes data from actual demand response programs. Sweden on the other hand does not have any existing demand response programs, but are showing an increased interest in adapting demand side flexibility services and could therefore gain knowledge from other more mature demand response markets. There are important differnces between U.S. and Europe that have been touched upon in the paper, in light of the case studies of California and Sweden. However, for future analyses, Sweden can not be studied separately from the rest of Europe since its market is becoming more fully integrated with the rest of the European countries.

There are obvious differences between Sweden and California (e.g. California having their peak demand during hot summer days, whereas Sweden has their peak on cold winter days). However, there is the possibility of using similar technologies for providing demand response. Furthermore, for the case of Sweden, more insulation and higher thermal inertia in buildings allows for other opportunities for pre-heating (or pre-cooling). Also a high market penetration of heat pumps contributes to possibilities of take and shift that are different from the California case. If and how different demand flexibility technologies can be enabled for automated demand flexibility is dependent on the market situation. Sweden has a fully deregulated energy market, whereas California has a deregulated wholesale market and a regulated retail market. The drivers for demand flexibility in Sweden are highly driven from a consumer/prosumer perspective, whereas in California demand flexibility is much more on the political agenda, and is viewed as an alternative to investments in new generation.

Conclusion and outlook

One of the upcoming challenges for Sweden is the integration of more wind to the system. Currently hydro is still a sufficient source to create load following to absorb the fluctuations in wind resources. To understand future need and value of demand flexibility in Sweden, a future scenario of hydro and its capability of meeting future need of balancing should be a good starting point for the analysis. It should be analyzed if hydro will be able to continue to cost effectively meet balancing needs or if there will be an increase in cost and environmental impact when more renewables are introduced, requiring more and other types of balancing services. Demand response is only going to make sense if it can provide flexibility to a lower cost and higher value than hydro does.

In order to move forward with research and demonstration on demand flexibility in Sweden, it would be valuable to develop a high-level quantification of the magnitude of the grid challenges that can be expected in the future. Such analysis is not available today. Therefore, a similar forecast and demand response potential study as the one that was carried out in California would be of interest also for Sweden. A high level forecasting tool could be developed that should enable answers and analysis for questions such as:

- If and when will Sweden have a need for demand flexibility?
- How much shape, shed, shift and shimmy of energy can be provided through demand flexibility and by which customer sectors?
- What are the demand flexibility technology needs, automation requirements, and enablement costs and economical value?

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