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Measuring the Intangible: An Overview of the Methodologies for Calculating Customer Baseline Load in PJM

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Highlights

• The introduction of explicit demand response (DR) in the electricity markets for energy, capacity and ancillary services requires a definition of the customer baseline load (CBL). Such counterfactual – that is, what the customer would consume in the absence of demand response – is necessary to measure the effective performance of a demand resource and to properly compensate the DR provider.

• Methodologies for CBL estimation should strike an adequate balance between various desirable criteria, including accuracy, simplicity and integrity. The choice of the best methodology among the several available depends on factors such as the function the relevant DR product performs in the system, the broader regulatory framework for DR participation in wholesale markets, and the characteristics of the DR providers.

• In the US, organised electricity markets have acquired significant experience with explicit DR and tested several CBL methodologies. The North American Energy Standards Board (NAESB) has defined five types of CBL methodologies to foster harmonisation and remove market barriers for new DR providers. The five types are maximum base load, meter before / meter after, baseline type-I, baseline type-II, and metering generation output.

• PJM has adopted different CBL methodologies, also depending on the specific market in which the demand resources are offered. To measure and verify the contribution of DR in day-ahead or in real-time energy markets, the default methodology belongs to the baseline type-I. Conversely, for frequency regulation and reserve, the adopted methodologies are of the meter before / meter after kind. Finally, to assess the contribution of DR in the capacity market, PJM resorts to maximum base load methodologies.

• European legislators currently debating the proposals of the Clean Energy Package could benefit from the lessons learnt in the past two decades by the organised markets in the US.

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1. Introduction

In an explicit demand response scheme, electricity customers can offer, individually or aggregated by an intermediary, to reduce their consumption, but the measurement of such reduction requires the identification of a baseline load. Since it is only possible to observe actual consumption, a counterfactual must be established.[1]

There are several ways to define a theoretical baseline consumption for customers participating in DR programmes. None of them is perfect or superior to the others in every aspect.

In this policy brief, we look at the almost two-decade-long experience of PJM, the largest regional transmission organisation (RTO) in the Eastern US. Different methodologies have been implemented there and refined over the years to ensure that electricity consumers could participate in the markets for capacity, electricity and ancillary services.

This experience, together with that of the other American RTOs and independent system operators (ISOs), can be valuable for Europe today. The rapid deployment of intermittent renewables, the desire to use resources efficiently and the ambition to empower customers led the European Commission to introduce the promotion of explicit demand response in the 2016 Clean Energy Package. The Council and the European Parliament are in the process of discussing the issue. Looking at what has happened on the other side of the Atlantic Ocean could provide useful insights and help to identify appropriate legislative decisions.

2. Why Do We Need a Customer Baseline Load?

The Federal Energy Regulatory Commission (FERC) defines demand response as:

"changes in electric 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".[2]

Thus, implementing a DR programme requires the identification of a customer baseline load (CBL), that is, an estimate of the electricity that would have been consumed by a customer participating in a DR programme in the absence of a DR event. A CBL provides a counterfactual against which to measure the effective load reduction provided by a demand resource. Without it, it would be impossible to verify the performance of the demand resource and settle the amount of money due to its provider.[3]

Correctly determining a CBL is nevertheless challenging. End-users' electricity consumption is variable for several legitimate reasons unrelated to DR programmes. Weather conditions, production schedules, seasonal variations in firms and household needs, holidays and other factors strongly

1. Several scholars argue that this problem would disappear naturally if customers providing explicit demand response were obliged to sign forward contracts for a specific energy profile over time or, alternatively, to compensate their energy supplier for the reduced consumption derived from the activation of demand response. See, among the most vocal on this point, Bushnell J., B. Hobbs and F. Wolak (2009), When it Comes to Demand Response, Is FERC Its Own Worst Enemy?, *The Electricity Journal*, vol. 22, issue 8, pp. 9-18; and Chao H. (2011), Demand response in wholesale electricity markets: the choice of customer baseline, *Journal of Regulatory Economics*, vol. 39, issue 1, pp. 68-88 . Such controversy is beyond the scope of this policy brief.

2. https://www.ferc.gov/industries/electric/indus-act/demand-response/dem-res-adv-metering.asp.

3. Common supply contracts offer the electricity customer an option to consume electricity up to a certain maximum level (capacity limit), but do not impose ex ante any specific consumption level.

affect the amount of electricity a customer will consume, independently from any price variation or DR incentive payment. CBL methodologies must take into account this natural variability and try to provide a calculation that is as accurate as possible, in order to avoid any over- or underestimation of the extent of demand response. Indeed, by overestimating actual demand reductions, a CBL may lead to higher participation in DR programmes but at a greater than necessary cost for the system and with the risk of procuring unreliable resources that might not deliver adequately when called into action. On the contrary, underestimation of demand reductions may deter customers from participating in DR programmes and lead to sub-optimal exploitation of demand-side resources.

However, accuracy is not the only criterion to judge a CBL methodology. A methodology should also be as simple as possible, to allow all the interested parties to calculate the baseline easily and rapidly. The provider of demand response, in particular, should be able to understand, possibly in real time, if a demand resource is complying or not with the obligations he or she has committed to. By adopting a simple methodology, the management costs of a DR programme can be contained and its attractiveness among end-users increased.

Finally, a CBL methodology must be in line with the DR programme's goals and must be able to cope with the information asymmetry that favours DR providers vis-à-vis the entity that manages the programme. DR providers know better than the entity managing the programme what the normal consumption patterns are and what is the effort they make to reduce demand in response to incentive payments or direct requests by the system operator. Besides, DR providers have an obvious incentive to act strategically in order to inflate their baseline and receive a higher compensation. Therefore, CBL methodologies must be robust to manipulation attempts and ensure the integrity of the DR programme.[4]

Successfully meeting all these criteria is difficult. Trade-offs are apparent. A sophisticated methodology, for example, can provide accurate estimates of normal consumption patterns but be so complicated to implement that estimations are available only after the end of the DR event, thereby reducing the programme's appeal to DR providers. Another methodology, on the contrary, may be simple to implement and rather accurate in its estimates but prone to gaming. Finally, a methodology may be good for verifying the provision of a service like frequency regulation but not at all suited to measuring the contribution of demand reduction in energy markets.[5]

There is hence a plurality of CBL methodologies and no one-size-fits-all solution. The best methodology to adopt will depend on several factors like the specific characteristics of the DR product in question, the rules of the relative programme and its participants. Type of event triggers, event duration and frequency, timing of notification, historical and current data available, presence of on-site generation at the DR provider's premises and the overall DR programme's goals (e.g., ensuring system reliability and adequacy) must all be considered, among other things.

4. For a discussion of the accuracy, simplicity and integrity criteria that should be satisfied by a good CBL methodology, see EnerNOC (2011), *The Demand Response Baseline*, White Paper.

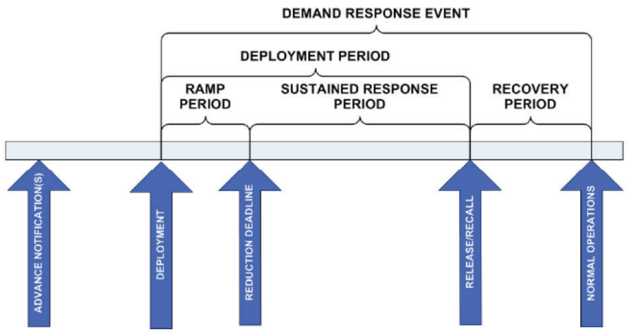
5. Measuring the contribution of a resource to frequency regulation is to some extent easier than the provision of energy or capacity. Assuming frequency regulation is a service designed to be energy neutral over extended periods of time, the contribution by a demand resource can be estimated by tracking short-term (e.g., seconds or less) variations in its consumption level.

3. The US Standard Classification of CBL Methodologies

Wholesale-market administered DR programmes have been deployed in the US since the beginning of the 21st century. ISOs and RTOs have used them to procure long-term capacity and ancillary services, introduce further competition in energy markets and reduce prices at peak-load times. Different baseline methodologies have been adopted. They can be distinguished by a number of elements: the definition of a static or a dynamic baseline; the use of historical load data from the individual consumer or the use of statistical sampling; the granularity of the consumption data used (daily, hourly or less); the length of the baseline window from which historical data are selected; the rules for excluding certain data from the baseline estimation process; the calculation type (e.g., averaging vs. regression); the use of baseline adjustments and caps; and so on and so forth.

The proliferation of methodologies increases the complexity of operating in the field of demand response, making the comparison of the solutions adopted by the various ISOs/RTOs more difficult for both customers and curtailment service providers (CSP).[6] The North American Energy Standards Board (NAESB), an industry forum for the development and promotion of standards in wholesale and retail gas and electricity markets, recognised that lack of harmonisation as a possible barrier to the further development of DR and the entrance of new players into the market. It thus developed a set of common definitions and practices that were later recognised by FERC (see Fig. 1 for some essential terminology).[7]

Fig. 1 – Demand Response Event Timing



Source: IRC (2008), Measurement and Verification Standards Wholesale Electric Demand Response Recommendation Summary, p. 17.

Five types of baseline methodologies were defined by NAESB:

- Maximum Base Load (MBL): "a performance evaluation method based solely on a demand resource's ability to reduce to a specified level of electricity demand, regardless of its electricity consumption or demand at deployment";
- Meter Before / Meter after (MBMA): "a performance evaluation method where electricity demand over a prescribed period of time prior to deployment is compared to similar readings during the sustained response period";
- Baseline Type-I (BT-I): "a performance evaluation method based on a demand resource's historical interval meter data which may also include other variables such as weather and calendar data";
- Baseline Type-II (BT-II): "a performance evaluation method that uses statistical sampling to estimate the electricity consumption of an aggregated demand resource where interval metering is not available on the entire population";

6. CSP is the name, in the US jargon, for entities that aggregate demand resources and participate on their behalf in wholesale markets.

7. See FERC Order no. 676-G of 2013.

Fig. 2 – Performance Evaluation Applicability

Performance Evaluation Type	Service Type			
	Energy	Capacity	Reserves	Regulation
Maximum Base Load	✓	✓		
Mater Before / Meter After	✓	✓	✓	✓
Baseline Type-I	✓	✓	✓	
Baseline Type-II	✓	✓	✓	✓
Metering Generator Output	✓	✓	✓	

Source: IRC (2008), Measurement and Verification Standards Wholesale Electric Demand Response Recommendation Summary,p. 61.

- Metering Generator Output (MGO) or Behind-the-Meter Generation: "a performance evaluation method, used when a generation asset is located behind the demand resource's revenue meter, in which the demand reduction value is based on the output of the generation asset".

Each of these types of methodologies has numerous possible variations. This is not the place for a detailed discussion of their implementation in the US wholesale markets, nor for an assessment of their relative pros and cons.[8] It is sufficient to say that: i) BT-I methodologies are those most commonly adopted, especially for measuring demand reductions offered in the energy markets; ii) MBL methodologies are often preferred for verifying the contribution of demand resources to capacity commitments; iii) MBMA methodologies are favoured when dealing with ancillary services (in particular frequency regulation); and iv) MGO methodologies are often used when there are on-site generation units (see Fig. 2 for the suitability of the various CBL methodologies to the different DR services).

4. The Case of PJM

PJM Interconnection is the largest electricity market in the US and was the first to embrace the participation of active demand resources in the early 2000s. Today, several DR products are available and demand resources connected to the PJM system are allowed to express offers to provide energy, ancillary services and capacity. Therefore, looking at PJM can provide a good example of how CBL methodologies have been concretely implemented in the US.

PJM does not use a single baseline methodology. On the contrary, different default methodologies

8. There are several studies that compare the various baseline methodologies and their relative advantages and disadvantages. The interested reader might look at: KEMA (2011), *PJM Empirical Analysis of Demand Response Baseline Methods*, Clark Lake, Michigan; EnerNOC (2011), *The Demand Response Baseline*, White Paper; Goldberg M.L. and G. Kennedy Agnew (2013), *Measurement and Verification for Demand Response*, DNV KEMA Energy and Sustainability. A mapping of the different products available to DR providers and the relative CBL methodologies, classified according to the NAESB standards, are reported for all the US ISOs/RTOs by the ISO/RTO Council (IRC) in the North American Demand Response Characteristics Comparison. The last edition was published in April 2016.

are used, depending on the relevant programme and the type of product. Besides, it is important to remember that alternative (ad hoc) methodologies can be agreed upon by PJM, the CSP and the electricity distribution company involved.[9]

Demand resources can participate in the **Economic Load Response Program** to offer energy (day-ahead or real-time) and ancillary services (regulation, synchronised reserve and day-ahead scheduling reserve).[10] In this case, the default methodology is the **3 Day Type with SAA**, as described in Section 3.3A.2 of the PJM Operating Agreement.[11] The methodology produces a baseline that can be classified within the Baseline Type-I and, more specifically, within the High X of Y category. This means that you have to look at the consumption levels of the most recent Y days that precede the day of demand reduction (event day); then you select, among these Y days, the X days with the highest load level. Days that are 'intrinsically' different from the day whose baseline is under estimation are not eligible to be considered as Y days (e.g., weekdays vs weekend days). Once the X days have been identified, the baseline is calculated for each relevant time interval, usually the hour, by averaging the respective load values in the X days. In this way, the baseline is sensitive to recent load patterns over days that are similar to the event day. Adjustments of the baseline that reflect specific weather or other load conditions on the event day are possible, in order to ensure that the baseline is not systematically overestimating or underestimating actual load patterns before the deployment of demand response.

As the name of the methodology suggests, baselines are computed in slightly different ways, depending on the type of the event day: weekday, Saturday, and Sunday/holiday.

The CBL of a weekday (i.e., Monday to Friday) is equal to "the average of the highest 4 out of the 5 most recent load weekdays in the 45-calendar day period preceding the relevant load reduction event". Not all the weekdays are eligible: holidays according to the North American Electric Reliability Corporation (NERC) and previous days where DR was activated cannot be selected. Furthermore, a weekday is excluded whenever the average daily event period usage is less than 25% of the average event period usage for the five selected days. If five eligible days cannot be found in the 45-calendar day period that precedes the relevant load reduction event, then, provided there are four eligible days, the CBL is based on the average of those four days. If even four eligible days cannot be found, then "event days will be used as necessary to meet the 4 days requirement, provided that any such event days shall be the highest load event days within the relevant 45-day period".

The CBL of a Saturday or a Sunday/NERC holiday is computed in almost the same way. The main difference is that instead of using the highest 4 of the 5 most recent load days in the 45-calendar day period, the highest 2 of the 3 most recent Saturdays or Sundays/NERC holidays are used.

A Symmetric Additive Adjustment (SAA) to the baseline is foreseen in order to take into due consideration the actual load patterns on the day of the event. Unless agreed otherwise, the adjustment is equal to the difference between the average usage estimated by the baseline and the average usage effectively recorded over the three-hour period that starts four hours before the beginning of the demand event. This difference, either negative or positive, is added to the baseline for all the hours of the demand response event.

9. Ad hoc methodologies are usually defined when the demand resource enrolled in the programme has a highly variable load pattern.

10. PJM Manual 11 on Energy & Ancillary Services Markets Operations, Section 10.2.

11. A presentation of the methodology is also provided in Section 10.4 of the PJM Manual 11 on Energy & Ancillary Services Markets Operations.

In the case of regulation and reserves, both synchronised and scheduled day-ahead, the CBL methodologies adopted are usually different from the 3 Day Type described above. Indeed, the demand resources providing these services are remunerated in order to change the amount of power they withdraw from the grid at short-time notice (almost instantaneously for regulation, within 10 minutes for synchronised reserve and within 30 minutes for reserve scheduled day-ahead), for a shorter time duration (from seconds to a few hours) and with a higher degree of reliability. Since the system operator is not interested here in the absolute level of the end-user's electricity consumption but rather in a precise change in the level of consumption, the baselines are generally of the **MBMA type**.

More precisely, in the case of synchronised reserve, the baseline for a specific demand resource is set by the consumption level measured at the start of the event. This value is then compared to the consumption level measured ten minutes after the start of the event. The difference between the two gives the demand reduction provided by that demand resource.[12] For day-ahead scheduling reserve, the contribution of demand response is verified in a similar way: the only difference is that the comparison is between the consumption level at the start of the event and 30 minutes after the start.[13] Coherently, demand response providing a regulation service is verified by comparing consumption four seconds before the signal and consumption immediately after the signal.

Besides the Economic Load Response Program, demand resources can participate in the **Emergency and Pre-emergency Load Response Program** and be compensated for reducing their load immediately prior to an anticipated emergency event or during an emergency event, upon request of the system operator. Various products are currently available to DR providers: they differ in the notification period, the maximum number of times and the months of the year in which the resource can be deployed, etc.[14] For each of these products, DR providers can choose the energy-only option, for which they receive an energy payment, the capacity-only option, for which they receive a capacity payment, and the full-programme option, for which they receive both an energy and a capacity payment.

To measure the actual contribution of demand resources participating in the Emergency Load Response Program various baselines are adopted by PJM. Without entering into details, it is sufficient to say that the energy contribution is measured by establishing a baseline that is usually the same 3 Day Type with SAA, used in the Economic Load Response Program, while the capacity contribution is normally measured by a baseline methodology of the **MBL type**. For instance, when a DR resource

12. See Section 4.2.11 of PJM Manual 11 on Energy & Ancillary Services Markets Operations. In order to allow for small fluctuations and possible telemetry delays, meter reading at the start of the event is defined as the greatest meter reading between one minute prior to and one minute following the start of the event. Similarly, a resource's meter reading ten minutes after the event is defined as the lowest meter reading achieved between nine and 11 minutes after the start of the event.

13. See Section 11.2.7 of PJM Manual 11 on Energy & Ancillary Services Markets Operations.

14. There are currently five products: limited DR, extended summer DR, annual DR, base capacity DR, and capacity performance DR. Some of them will be phased out in the coming delivery years, while others have been just recently introduced. See Liu Y. (2017), Demand response and energy efficiency in the capacity resource procurement: Case studies of forward capacity markets in ISO New England, PJM and Great Britain, *Energy Policy*, vol. 100, pp. 271-282.

chooses to commit to a Firm Service Level (FSL),[15] then a static baseline called Peak Load Contribution (PLC) is used. This baseline is computed by averaging the customer's consumption recorded during the five highest peak hours of the five highest peak days on the whole PJM system during the previous summer (the so called 'five coincidental peaks').[16]

5. Conclusions and Policy Recommendations

The almost 20-year long experience gained by PJM Interconnection with explicit demand response undoubtedly provides insights for the EU in the context of the current debate on the Clean Energy Package and the electricity market design it contains.

Focusing solely on the issue of a customer baseline load estimation, the following recommendations may be derived from the case of PJM:

- The successful integration of explicit demand response in the electricity markets requires the adoption of methodologies to estimate what the DR provider would consume in the absence of the DR event;
- Several different methodologies to estimate the customer baseline are possible. When deciding which one to adopt, the entity managing the DR mechanism should try to strike an adequate balance between accuracy, simplicity and integrity. The choice should also be made taking into account the specific characteristics of the relevant DR product, the function it plays in the overall electricity system and the characteristics of the end users that will participate in the mechanism.
- For energy-related products, a good baseline can be estimated on the historical consumption data of the DR provider, taken from the days that immediately precede the day of demand response deployment. On the contrary, in the case of the ancillary services provided by demand resources, the baseline can be better approximated by looking at the difference between the consumption level immediately before and immediately after the activation of the resources. Finally, for capacity-related products, a customer baseline can be identified from the peak consumption levels recorded in the previous year by the DR provider and coincident with the peak load for the overall electricity system.

15. When providing a firm service level (FSL), a customer must reduce its load to a predetermined level after receiving the notification from the CSP's market operation centre. That level must be lower than the amount of capacity reserve for the customer as represented by the PCL. FSL is the compliance measurement method chosen by the vast majority of DR resources participating in the PJM capacity market. See PJM (2016), *Load Management Performance Report 2016/2017*, pp. 5-9.

16. See Attachment A of PJM Manual 19 on Load Forecasting and Analysis.

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