

## THE ADDED VALUE OF HOUSEHOLD LEVEL ANALYSIS IN ACTIVE DEMAND: USING PSYCHOLOGICAL CONCEPTS IN UNDERSTANDING CHANGING ELECTRICITY CONSUMPTION BEHAVIOUR

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### ABSTRACT

Active Demand [AD] pilots are now being setup and performed all over the globe and particularly in Europe. This approach is seen as one of the solutions that will facilitate the stability of electricity systems. The essence of AD is that flexibility is sought on the demand side of the supply and demand equation. AD has as a consequence that consumers, and in this paper these are households, are requested to change their electricity consumption behaviour, both in volume and time. The ADVANCED project is a EU funded research initiative that has as goal to understand and share the factors involved in AD. This research combines technical and social scientific approaches in one project. The identification of determinants of household behaviour change requires a methodology and measurement instruments. In this paper we elaborate on the methodology and a few key measurement features. We introduce new Key Performance Indicators [KPIs] of behaviour change based on actual hourly electricity consumption behaviour and associate these with psych-social concepts to explore determinants of the intended behaviour changes. We demonstrate how this works and conclude that standardisation of methodology and instruments across AD pilots would greatly enhance the understanding of what facilitates Active Demand.

### ISSUE

This paper provides a proven methodology for Active Demand [AD] pilot evaluation on a household level and shares the first preliminary analysis results of the ADVANCED<sup>1</sup> (Active Demand Value ANd Consumers Experiences Discovery) project. The members of the

ADVANCED consortium define AD as "providing electricity consumers with information on their consumption and the ability to respond to time-based prices (either manually or automatically) as well as with other types of incentives, thus motivating them to actively manage their consumption by altering usage in line with the network conditions, such that modifications in consumer demand become a viable option for addressing challenges of electricity systems".

AD pilots are performed all over Europe. These pilots test the technological, behavioural and commercial aspects of AD principles as one of the solutions to the problem of increasing variability in supply of electricity (production) due to the growing proportion of renewable electricity generation and to contribute to operation and investment efficiency in the system. A stable electricity system is a prerequisite for continuity of service; peak clipping / valley filling are mechanisms that have been identified to contribute to stability. Peak clipping is achieved by temporarily reducing consumption (demand) at a particular point in time, conversely valley filling is achieved by temporarily increasing consumption (demand) at another particular point in time. In other words, consumers, in this paper residential consumers, are urged to consume when electricity is available in abundance and urged to reduce consumption when electricity is scarce.

In order to achieve changes in household behaviour various interventions have been developed and explored within pilots (often in combination to maximise impact). Some pilots provide households with feedback through for instance a smart energy display making energy and its consumption visible, thus expanding on residential consumers' awareness as a prerequisite to reducing the quantity of energy consumed in the household. In other pilots the focus is automation, where the choice to consume is delegated to an algorithm communicating with smart appliances. The focus may also be on the implementation of time-sensitive tariff structures. Two major behavioural changes are targeted, 1) an overall reduction in electricity consumption and 2) matching the consumption of electricity with network needs. Concretely this means that households, will have to

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<sup>1</sup> ADVANCED (Active Demand Value ANd Consumers Experiences Discovery) is a research project cofounded by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 308923, that aims to shed light on ways to overcome the barriers hindering the mass deployment of Active Demand (AD) in Europe. The sole responsibility for the content of this paper lies with the authors. It does not necessarily reflect the opinion of the European Union. The European Commission are responsible for any use that may be made of the information contained therein.

change their habits e.g. when to run the washing machine, , when to reduce usage of heating or air-conditioning etc.

For both behavioural changes Key Performance Indicators (KPIs) need to be formulated and implemented at the household level to test how the various interventions (smart displays, smart appliances, pricing strategies etc.) actually contribute to the change in behaviour of the households. The potential benefits of AD and the methodology to quantify a broader set of KPIs used for the ADVANCED project are described in the report D1.2 [1].

The current practice for evaluating the effectiveness of AD technologies is based on analyses at the pilot level, gaining insights on aggregated flexibility (the average of a group of households) for the system level.

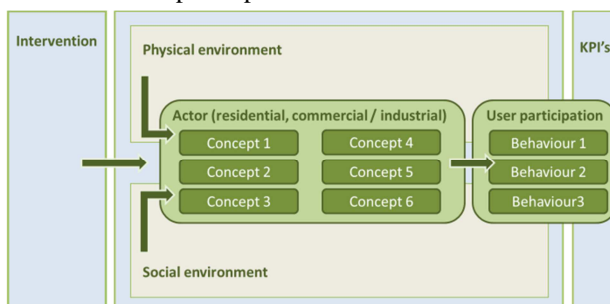
However, this does not make explicit what drives a single household to change its behaviour. **Identifying these psycho-social drivers would enable the fine tuning of interventions and thus facilitate more successful AD.**

## APPROACH

By introducing objective measurements at the household level which reflect the overall consumption and the flexibility of consumption in time and correlating these with psycho-social concepts also measured at the household level, significant determinants of the intended behavioural change can be identified.

## Theory

Relevant determinants, derived from various behavioural theories and/or operational practice<sup>2</sup> are identified in the ADVANCED conceptual model for active end-user participation.



**Figure 1: The ADVANCED conceptual model**

The overall theoretical framework is depicted above. *Interventions* leverage *Actor Concepts*; actors live in a

*physical environment* and *social environment* influencing their behaviour and their *behaviour* is reflected in *KPIs*. For a more detailed elaboration of this model, the associated concepts and the hypothesis formulated on the relations between these concepts the reader is advised to read the ADVANCED report D1.1 [2].

## Methodology

In order to empirically explore and establish associations between household behavioural change (reduction of usage and flexibility) and certain psycho-social concepts it is needed to operationalize these various concepts into measurable variables. This is explained in more elaborate detail in the ADVANCED report D2.2 [3]. This has been done in the following manner.

## Cross-sectional data

One or more surveys were held with the participating households in the pilots. These surveys included numerous psycho-social questions; tapping various psycho-social concepts like attitude, value orientation, self-efficacy, social norm, trust in the utility, etc. in conjunction with the more usual demographics such as age, gender, household size etc. Usually the household responses were measured with Likert type scales (ordinal data) but also include nominal scales or plain numeric values. It has to be noted that the participating AD demonstration pilots were designed prior to the ADVANCED project and all used their own methodology and instruments to achieve their pilot objectives. The ADVANCED project aims to capitalize on these separate experiences and find communalities or differences that help understand which factors (potentially) contribute to the two intended behavioural changes. We also have to note that because the ADAVANCED database is being populated with data collected in the context of the local pilot projects, we have paid considerable attention to not infringe local privacy rules and are successful in that. This is a study in itself, for more detail please read the Cired Paper "Privacy in Active Demand Systems"[4].

## Longitudinal data

In principle the smart meters registered the amount of electricity used [Wh] per household per hour of the day for the duration of the pilot and, in some cases, also in an equivalent period preceding the pilot. This generates longitudinal consumption data per household.

In order to correlate the consumption data (longitudinal) with the psycho-social variables (cross-sectional) the consumption information needs to be expressed in aggregated variables (KPIs) which then could be correlated with the psycho-social variables. In the next section this will be explained in more detail.

<sup>2</sup> The ADVANCED pilots ENEL Info+, E-DeMa (RWE), ADDRESS pilot sites (Iberdrola and EDF/ERDF) and the VaasaETT database containing meta-analyses data of other 100 AD pilots, involving 450,000 residential customers.

**KPI change in overall electricity consumption.**

The computation of this KPI is quite straightforward. It represents the overall increase or decrease in electricity consumption of the households when comparing the pilot period consumption of electricity with the equivalent pre-pilot period and is expressed in percentages of increased or decreased usage. This generates one value for *KPI change in electricity consumption* per household whereby the value indicates the rate and the sign indicates an increase or decrease in overall usage. These values are then analysed together with the cross-sectional data (psycho-social variables).

**KPIs Flexibility**

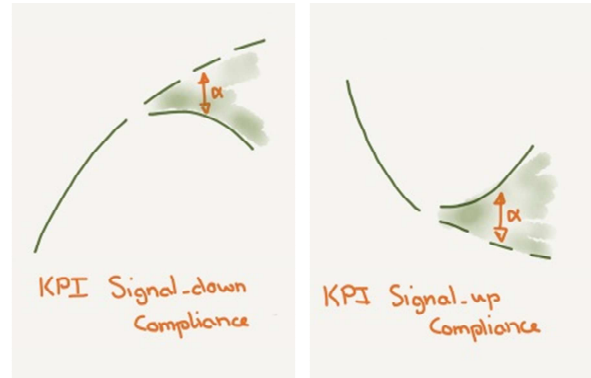
In the pilots, information is provided to the households to encourage them to offer flexibility. This signal information takes on two forms, either a household is requested directly to use less, or more electricity or indirectly through a change in tariff or offering some kind of incentive. A change to a lower tariff/higher incentive can be considered as a signal to use more; conversely, a change to a higher tariff/no incentive, as a signal to use less. For the pilots involving flexibility of demand the onset of the signal at the beginning of the hour is used as the marker for those hours that households are requested/urged to change their consumption behaviour. They are either urged to use more (signal = +1) or urged to use less (signal = -1), when there is no change, signal =0.

It is known that households show specific patterns of usage. These are reflected in load curves which are usually represented as Wh per hour in a 24 hour cycle. In most evaluations of AD pilots these load curves are aggregated to the pilot level and then compared to other average load curves (either historical or an analogous control group). It is then common practice to compare the mean electricity consumption for the hours households are requested/urged to change their consumption behaviour with a reference consumption. The differences in consumption then are used to establish the *KPIs Flexibility Up* and *Flexibility down*.

These KPIs however do not measure behavioural change due to a signal, and therefore are not suitable for the purpose of this paper study. Furthermore, variance at the household level is needed to be able to correlate with psycho-social concepts, also measured at the household level to ascertain levels of association.

To mitigate the above mentioned problems, a new *KPI Signal compliance* is defined. Given a reference (historical) load curve of a household (habitual behaviour) it can be calculated whether or not a household concurrently complies (for each hour signal = +1 or -1) with a request to use more or less electricity by calculating the difference between the habitual increase or decrease% in usage in this timeframe (based on the reference load curve) and compare this increase or

decrease with the concurrent increase or decrease% in usage. A sign is assign to that rate [ $\alpha$ ] in which + indicates compliance and - indicates non-compliance.



**Figure 2 : KPI's Signal down and -up Compliance**

For each household this down and up compliance is calculated for the signal hours and the average over the signal hours within a household.

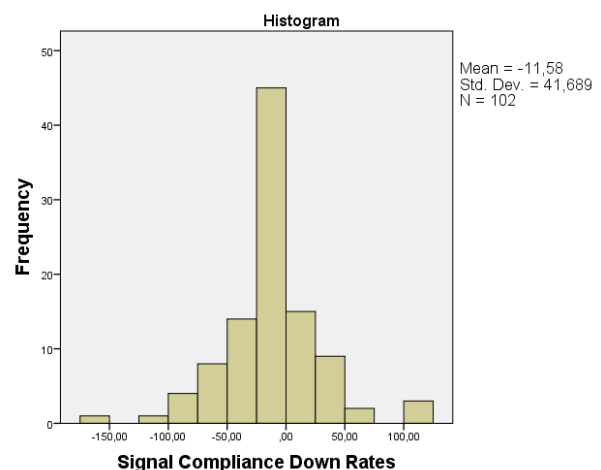
In this manner an aggregated *KPI Signal Down Compliance* value and a *KPI Signal Up Compliance* value is defined, which can then be analysed together with the cross-sectional data (psycho-social variables).

**RESULTS**

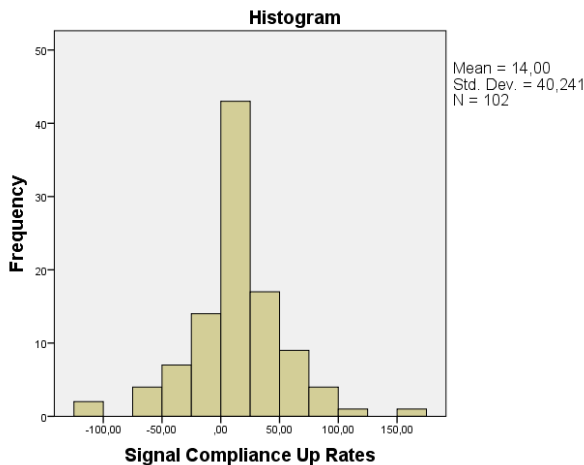
Before going into the association between psycho-social concepts and behavioural change some assurance on the applicability of the above mentioned methodology, and in particular of the KPI calculation method for signal compliance is given.

**Applicability Check**

Looking at the extent to which households of one pilot on average complied with the down signal, it can be seen that households have changed their behaviour, but in the opposite (wrong) direction, they have actually increased their *usage* by 12% during the period where they were asked to decrease usage.



For the up signal condition the households do comply with the signal, they have increased their usage by 14%.



The ADVANCED project is currently in the phase of adding additional data to its database to explore the factors to which the above results can be attributed.

### Correlations

With these KPIs in place and the database filled with data the various hypotheses that have been initially formulated in the conceptual model can be explored. In the next section some results of these explorations are presented.

#### **KPI Change in overall electricity consumption**

Some concepts directly relate to the KPI *Change in overall electricity consumption*.

The *annual consumption* is inversely correlated with *change in overall electricity consumption* ( $r = -0.349$  and  $r = -0.370$ ), which suggests that households with a higher overall consumption have a greater likelihood in electricity savings than households with a lower annual consumption.

Households that initially have said to *frequently wash over 70°C* also show a greater *reduction in overall electricity consumption* when compared to households that infrequently wash over 70°C ( $r = -0.270$ ).

Households with a higher *average age* show a greater likelihood to *reduction in overall consumption* ( $r = -0.106$ ), and *house ownership* also is indicative of an overall reduction in consumption ( $r = -0.262$ ).

#### **KPI Signal compliance**

The greater the *number of days the households participate* in the pilots is indicative for more *down signal compliance* (use less when requested;  $r = 0.303$ ) but not for *up signal compliance* (use more when requested;  $r = -0.207$ ).

It has been found that *Home ownership* has no relationship with down signal compliance but does have an inverse relationship with *up signal compliance* ( $r = -$

0.240). In other words, people who rent are more likely to comply to use more electricity; conversely, people who own are less likely to comply in using more electricity.

The type of *value orientation of a household, monetary or environmental* is associated with *signal up compliance* ( $r = -0.234$ ). Households intrinsically motivated by savings are more likely to increase usage upon request than households with an intrinsic environmental drive.

These are some examples of the explorations, new data and analysis will be added in the remainder of the ADVANCED project.

### **IMPACT**

It has been argued and demonstrated that household level analysis is a prerequisite for gaining insights in the behavioural drivers behind AD. This requires a multidisciplinary approach; in other words, complementing technological advancements with psycho-social and behavioural knowledge. This resulted in a methodology that combines smart meter data collection with behavioural change insights by means of a newly developed KPI, *Signal Compliance*.

It has been seen that standardizing the variables and corresponding unit of measurement enable cross case analyses. However, because the pilots were initially organised for their specific local purposes they were not configured with respect to experimental design and the measurement instruments were not used in a uniform manner. In the exploration and validation the variables needed to be standardised to an ADVANCED format, resulting in an ADVANCED knowledge base. In this transformation process information is lost, which would not have occurred if a uniform methodology would have been used.

It is therefore advised all future European AD- pilots to use a minimal set of standardised measurement instruments (for both KPIs as key variables) to enable cross case analysis. The ADVANCED project will propose a set after the in-depth analyses phase is completed.

Furthermore, the empirical validation of consumption KPIs has shown that having historical data at the same level of resolution (hourly at most) as during the pilot is of considerable advantage because this allows for calculation on a household level of the flexibility and signal compliance KPIs. It is demonstrated that it is possible to detect behavioural change of households based on their consumption data and signal information. This is important when incentives for 'environmental conscious behaviour' are given to households.

It is advised to future active demand pilots to capture historical data to generate a baseline (reference load

curves) per household.

More general it is noted that the data involved in AD technologies is subject to privacy issues, and hence also the analysis discussed here. In ADVANCED the impact of privacy issues and appropriate countermeasures is also part of study, see [4].

These uses of the KPIs then allows correlating various (standardised) psycho-social variables with the actual behaviour and thus generate insights with respect to determinants of behavioural changes, the first step in understanding which mechanisms are involved in achieving active demand, in other words realising electricity consumption reduction and shifting households consumption in time. The exploratory analysis of the available standardised data allows to do exactly that. Furthermore, the KPIs allows the comparison between different interventions and pilot set-ups in their effectiveness on changing household behaviour.

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