Assessing the economic benefits of flexible residential load participation in the Dutch day-ahead auction and balancing market

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***Abstract*--In this paper the authors present the potential cost-savings that may arise due to demand response from residential customers participating in the Amsterdam Power eXchange (APX) day-ahead auction and the Dutch balancing energy market which is organised by TenneT, the Dutch Transmission System Operator (TSO). For this purpose, a model for residential demand response is developed that utilises as input historical market data. Furthermore, the model synthesises a daily load profile based on load profiles of Dutch residential customers and simulated data to represent aggregate demands of domestic appliances and electric vehicles. The model is built around the concept of the aggregator, an envisioned legal entity, that contracts large amounts of residential customers and then coordinates them in real-time under different objectives (i.e. economic optimisation based on predicted day-ahead prices and the provision of balancing energy). Simulation results show that the potential economic benefits of residential demand response, on the Dutch electricity markets, is relatively low on a per household basis, but not negligible for the business case of the aggregator.**

***Index Terms*--Power system economics, day-ahead auction, secondary reserves, supply and demand, aggregator, residential demand response, optimal scheduling, domestic appliances, and electric vehicles.**

I. Introduction

A significant increase in the penetration of renewable energy generation within the power system of the Netherlands and other countries is expected in the near future. As more electrical energy will be generated by intermittent renewable sources, random mismatch between generation and load will increase, because it will no longer be driven only by the fluctuations of the load. In this context, maintaining the system balance will become an even more challenging task. Until now, power system control was mainly performed by adapting the supply side (supply follows the demand) and minor attention was paid in controlling the demand side. However, as our society moves away from flexible fossil-fuelled generation, part of the flexible generation capacity that is available today will be replaced by intermittent energy sources in the future. Therefore, all available resources for balancing purposes should be considered, and it is expected that the demand side will also adjust to the supply side [1]. The implementation of demand response mechanisms may provide a considerable option to reshape the demand for electrical energy.

Demand response represents the outcome of an action undertaken by electricity consumers in response to a stimulus. In a resource or transport constrained power system where the option of changing supply to balance demand is limited and/or available at high cost, residential demand response can contribute to maintain a balance between supply and demand by utilising a resource that is latent in the system. The potential of residential demand response can be significant, but its exploration still remains a challenge. Most of the programs that have been implemented today are price varying programs, such as time-of-use and critical peak pricing programs, while real-time pricing programs are envisioned for the future. In this work residential demand response is analysed in economic terms, while focusing on the Amsterdam Power eXchange (APX) day-ahead auction and the Dutch balancing energy market. Based on current data about domestic electricity use and travel behaviour, and assuming a certain penetration of electric vehicles, a realistic representation of the Dutch residential load in the near future is generated. Three different scenarios were developed and utilised in simulations to examine the potential benefits of active participation of residential customers in the Dutch electricity markets. The simulation outcome is analysed in an effort to quantify the potential economic benefits of residential demand response in the Netherlands.

The paper is constructed as follows: in section II, residential loads are classified according to their characteristic load profile; this classification is necessary for defining the control strategy that is utilised in the model. In section III, a description of the developed model is provided and the utilised control strategy is explained. In section IV, the three developed scenarios are presented and the simulation results are evaluated. The paper ends with conclusions.

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II. Load Classification and Representation

Total electricity demand in a household consists of aggregate power consumption of individual appliances. According to [11], domestic appliances can be classified into different categories: cold appliances (refrigerators (RF), and freezers (FR)), wet appliances (washing machines (WM), tumble dryers (TD), and dishwashers (DW)), and brown appliances (TV, audio and video), cooking, lighting and miscellaneous appliances. Since the focus in this investigation is to assess the potential of the residential demand side for demand response, apart from the aggregate demand it is important to create an insight into the part of the demand that can be characterised as responsive. Fig. 1 shows the share of electricity consumption from domestic appliances in an average Dutch household [12]. The focus in this paper is on 'pure' electric appliances, therefore heat demand in households which is supplied by natural gas combustion in boilers or from co-generation technologies is out of the scope.

Demands (loads) can be characterised as critical (non-flexible loads which are difficult or impossible to be displaced in time and amount without creating a sense of discomfort to the consumers) or non-critical (loads which are characterised by some degrees of flexibility). In practice, while focusing on domestic appliances, the operation of a refrigerator can be considered non-critical for a user (as long as the inside temperature is ranging within acceptable limits to preserve the food), while the operation of a desktop personal computer which is directly connected to the mains, excluding the use of a battery back-up, can be considered critical. Thus, the expected load profile of an individual customer at a certain time can be decomposed into the following categories with respect to controllability:

- Non controllable part of the load (base load)
- Controllable part of the load (flexible load)

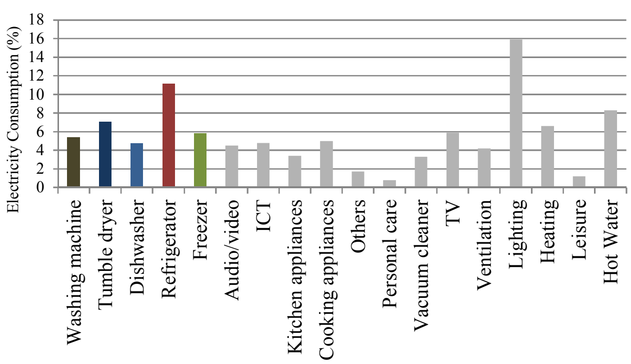

Fig. 1. Electricity consumption of domestic appliances for an average household in the Netherlands [12].

A. *Uncontrollable Loads (base load)*

In order to assess the economic potential of residential demand response, it is important to create a realistic representation of the residential load in terms of energy volumes and time schedules. The base load profiles that are incorporated in the model (see Section III), were constructed based on representative electricity consumption patterns from a sample of Dutch households, and were verified based on actual data from a Dutch Distribution System Operator. Noticeable, the constructed base load profiles do not include the contribution of flexible loads which are treated separately, and are discussed in the following section.

B. *Controllable Loads (flexible loads)*

To evaluate the amount of electricity demand of a household which can be considered as flexible, it is important to know the composition of the load profile of the proposed consumer. If residential loads are going to be utilised in demand response schemes (e.g. through Time-of-Use programmes), the overall satisfaction of consumers should not be affected. Therefore only specific loads may be considered as flexible that can be shed for example in response to requests from the system operator or even autonomously by detecting network signals or price variations. Flexible loads may include wet and cold appliances, which are potential appliances for employment in demand response schemes [1]. Considering the Dutch case, approximately 34% of the average domestic electrical energy consumption is attributed to wet and cold appliances and this is illustrated in Fig. 2.

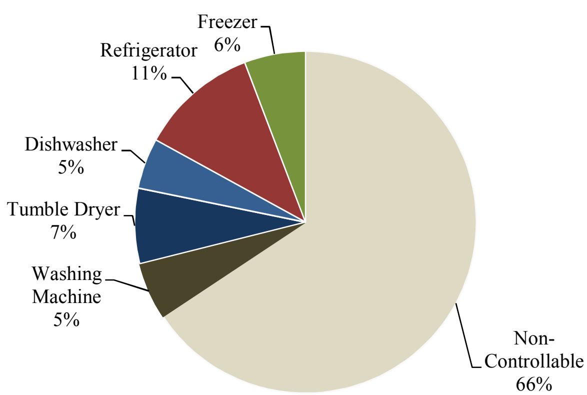

Fig. 2. Electricity consumption of flexible and non-controllable loads for an average Dutch household [12].

Furthermore, when constructing aggregate load profiles for residential customers, it is important to incorporate figures about the penetration level of the different appliances. Penetration levels refer to the appliances ownership rates, and are illustrated in Fig. 3 for wet and cold appliances and for the case of an average Dutch household.

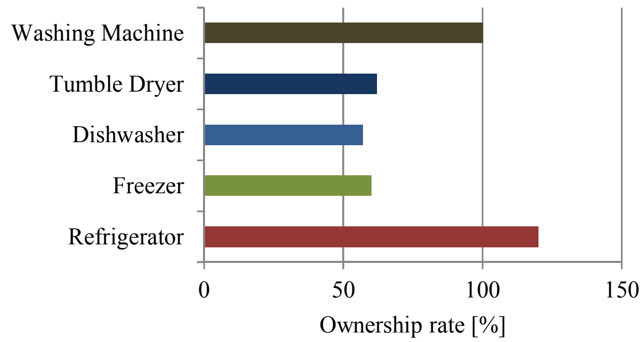

Fig. 3. Penetration level of specific domestic appliances in an average Dutch household [4].

When modelling the flexible domestic loads, it is important to consider the consumer behaviour. This investigation incorporates load profiles and probabilistic distributions (based on appliances' start-up probabilities) which are an outcome of the SMART-A project [3]. Overall taken, when modelling the aggregate residential load, the following factors are considered:

- Number of households
- Ownership rate of appliances (penetration levels)
- Start-up probability of appliances
- And the characteristic load profiles of the appliances

With the prospect of an increasing number of electric vehicles (EVs) in the near future, domestic charging will be the most obvious way to recharge the batteries of the EVs, due to lack of public charging infrastructures. For utilities and grid operators, the delivery of power for charging the batteries of EVs provides substantial opportunities and challenges [13]. By controlling the charging process of the EVs' batteries, the concept of electric transportation can provide the means to balance supply and demand, to optimise the use of grid assets and to minimise distribution energy losses [1], [13].

The charging power profiles which are presented in [2], and were developed based on transport data of the Dutch population, are adopted for this investigation. These charging power profiles are addressing two distinct cases, 'plug at work' and 'no plug at work' in the near future. Since the scope of this investigation is to assess the potential benefits of residential demand response, the charging profiles which refer to domestic charging ('no plug at work') are utilised as input in the developed model. Furthermore, the authors in [2] have defined a capacity factor to capture the available flexibility for Demand Response of the aggregate charging power profile. The capacity factors are figures in (kW) that are calculated based on a finite-state-model [2]. These capacity factors are also incorporated in the developed model to represent the maximum load reduction per device in a 15 (min.) basis that can be actuated given specific constraints. These constraints are related to the State of Charge (SoC) of the batteries (i.e. SoC > 85% to allow interruption of the charging process), and the users' requirements such as driving patterns and vehicles' availability (based on statistical transport data for the Netherlands). Note, that in this investigation, charging the batteries is only considered as a controllable and flexible load process. Due to uncertainties related to battery performance, lifetime and ownership, discharging the batteries to inject power back to the grid is left outside the scope of this research.

C. Demand Response Options

Residential demand response exploits a resource already present in the system. It would be ideal if its utilisation would require little or no user intervention during planning and operation (automated functions), while both the users and system requirements are respected. In order to capture these constraints two demand response options, provided by residential loads, can be distinguished: load shifting and load interruption both leading to load increase/reduction but the latter without notice. For these two options a qualitative overview of the potential of residential loads to contribute in demand response schemes, is given in table I for the investigated loads.

1) Load Shifting: refers to the option of bringing forward or postponing the load cycles of appliances (limited by consumer's involvement). This option refers to shifting the full load cycle and it is applied for wet appliances and electric vehicle.

2) Load Interruption: The option of interrupting the load cycles of specific appliances for short time periods which do not compromise significantly the quality of service; this option is applied to loads that are in operation and their cycle is interrupted. It is applied for electric vehicles and cold appliances.

TABLE I
POTENTIAL CONTRIBUTION OF RESIDENTIAL LOADS FOR DEMAND RESPONSE

	Demand Response Options	
Loads	Load Shifting	Load Interruption
Wet appliances	High	Low (due to thermal loss)
Cold appliances	Low (due to low thermal inertia)	High
Electric vehicles	High	High

D. Time Constraints for Demand Response

For the execution of residential demand response the acceptance of consumers is a key factor. Analysing the consumer acceptance of smart domestic appliances, it seems that the acceptance depends on the respective device and cannot be generalised over all domestic appliances [3]. The results in [3] suggest that shifting the operation of an electrical load is realistic for duration between 0.5 and 3 (hours). In the case of duty cycle appliances, such as refrigerators and freezers, acceptance is given only if comfort is not lost and users keep full control over the devices, therefore a conservative approach is chosen; to interrupt the cycles only once per day. It is also possible that the start of the cycle is brought forward instead of postponed. In the case of electric vehicles, the charging process can be interrupted only when the State-of-Charge (SoC) is above 85% and this assumption is based in the results from [2]. To account for consumers comfort, a variable shifting time during the day was assumed and applied for the case of electric vehicles, and this variable shifting time is based on consumers' behaviour. For example during the day there is more activity related to passenger transport compared to the night and early morning hours. The maximum allowed interruption/shifting time is referred as T_{max} and table II summarises the assumed T_{max} values for all the investigated loads.

TABLE II
THE ALLOWED MAXIMUM INTERRUPTION/SHIFTING TIME FOR ALL INVESTIGATED RESIDENTIAL LOADS

Appliance	Period	T_{max} (hours)
Wet	Once a day	3
Cold	Once a day	0.25
Electric Vehicles	07:00-19:00	1
	19:00-21:00	2
	21:00-05:00	4
	05:00-07:00	2

Each appliance (electrical load) has specific constraints and attributes. Refrigerators and freezers are characterised by a duty cycle operation and require almost no interference with the user, while the main objective is to operate within acceptable temperatures inside the compartment to preserve food in good conditions. Other load processes are characterised by different constraints, such as the SoC of the EV battery which can introduce limitations during driving, since a minimum amount of energy content has to be stored in the battery to fulfil the energy requirements of the next trip. For wet appliances, the maximum power demand during a washing cycle occurs when the water is heated up. Interrupting the washing cycle after the process of heating the water will result in increased thermal energy loss, and when the cycle is resumed, there will be a need for additional energy input. Following this analysis, it becomes apparent that the available capacity for load shifting actions varies during the day, as a function of user behaviour and loads' technical characteristics.

III. MODEL DESCRIPTION

In Fig. 4, an overview of the residential demand response model is given. The developed model is split up into three main parts (and more sub-components) which are further explained below: the data input, the profile generator and the optimisation process.

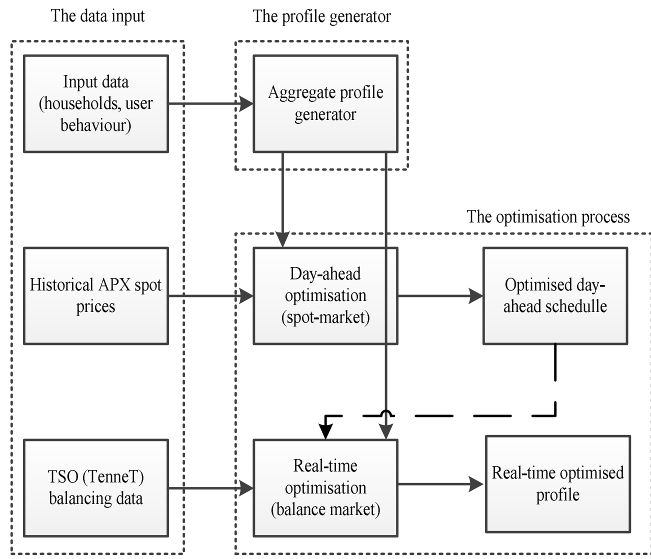

Fig. 4. Overview of the developed model.

A. Input Data: Households and User Behaviour

The data about residential loads that are discussed and presented in the previous section are utilised as input in the load profile generator. The outcome is the load profile which is illustrated in Fig. 5, and consists of a realistic representation of the daily aggregate residential load for the Dutch case study in the near future. This aggregate load profile is a product of synthesis of various data sources and simulation results and is further utilised in the optimisation process.

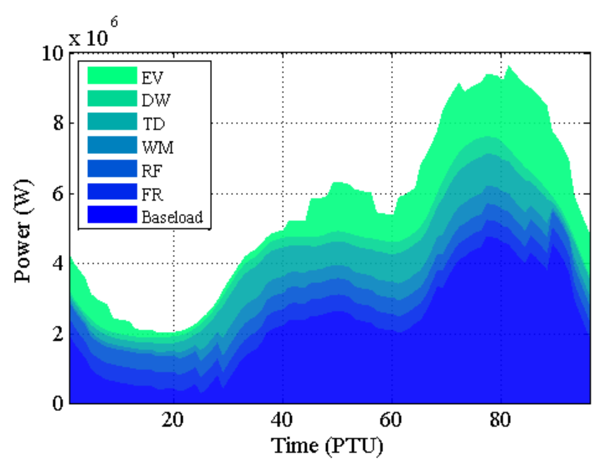

Fig. 5. The synthesised aggregate load profile of 10 000 Dutch households.

B. Input Data: Historical APX Spot Prices

The operation of the Dutch day-ahead spot market is managed by the Amsterdam Power eXchange (APX); this market is based on a two-sided auction model. APX receives supply and demand bids for every hour of the next day and settles a clearing price and volume. In Fig. 6, the development of the APX spot prices in 2010 is shown. The APX historical prices are utilised as input in the day-ahead optimisation process. The model algorithm has the possibility to optimise the available resources on both markets, first at the APX day-ahead spot-market, and subsequently at the Dutch balancing market, and this is illustrated with the dashed arrow in Fig. 4.

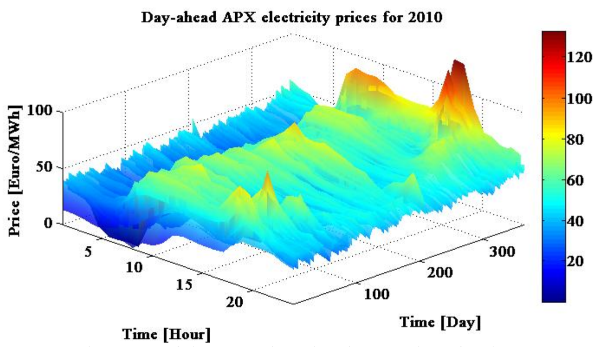

Fig. 6. Development of the APX day-ahead spot prices for the year 2010.

C. Day-Ahead Optimisation Process

The model calculates for each type of appliance the number of devices that are starting their operation in each particular Program Time Unit (PTU), which is defined as a 15 (min.) time interval. Afterwards when the model is run with the objective function of total cost minimisation, the model will give an output for each group of appliances with a different time of starting operation. Since the details of individual appliances will not always be visible, some approximations have to be made to capture the constraints originating from the end-use of electricity. It is important during the optimisation process to allow the utilisation of the resources that are attributed to the previous day (of the simulated day). To capture this phenomenon simulation is executed for a time period of 3 days; first day is for model initialisation and the last day for the full recovery of load which was shifted during the second day. Furthermore, active participation of a large number of customers (millions of households) in the spot market is expected to influence the market clearing prices. Therefore it was decided to limit the number of participating households in the day-ahead scheduling to a number of 10 000. The model displaces the available flexible load from high price periods to low price periods. Note that the model has a limited amount of resources to shift further in time during the night hours (e.g. from 00:00 to 7:00) and this has to do with the number of scheduled appliances during the night.

D. Input: TSO (TenneT) Balancing Data

In the Netherlands, TenneT, the national TSO, is the responsible authority to ensure the continuous balance between generation and load and to maintain the security of supply. It takes primary (fast), secondary and tertiary (less fast) control actions to stabilise frequency deviations and to maintain the programmed exchanges with other control areas. For that purpose, TenneT has set up a single-buyer-market for secondary and tertiary reserves to be able to perform its tasks [14]. By utilising TenneT public market data about the system imbalance, with 15 (min.) resolution [6], the model looks only in the current time interval (i.e. current PTU) and acts according to the system imbalance. The domestic appliances are in this case left out of the program. Due to the limited flexibility that they can offer in real-time it was decided only to assess the potential benefit of interrupting the charging process of electric vehicles for the provision of operating reserves (balancing energy).

E. Real-Time Optimisation (balancing market)

For the real-time optimisation, the model is provided with TenneT data, about the system imbalance in each particular PTU and the direction of this imbalance (up or down regulating/reserve power). Furthermore, the real-time optimisation algorithm incorporates the capacity factors of EVs (the available capacity to perform load reduction). The real-time optimisation algorithm utilises a different number of participating households, compared to the day-ahead optimisation. This is related to the minimum capacity requirements for placing bids in TenneT balancing market [14]. For regulating and reserve capacity the minimum accepted bid size is 4 (MW). Therefore, it was decided to run the simulation for the real-time optimisation assuming that 30% of the Dutch households (from a total of 7.2 million households) participate in TenneT balancing market, where each household owns an EV. Most probably such a large participation will affect market prices. Still, it is highly uncertain how the participation of the demand side impacts electricity prices since those are highly dependent (among others) to the marginal costs of generation. For this reason, but also due to the utilisation of historical market data, the price impact was omitted while investigating the large-scale participation of residential customers in both the spot and real-time balancing markets.

The model distinguishes between the different operating states of the Dutch power system. In the case that the system is long (more supply than demand), then the model performs a load increase. Contrary, when the system is short (more demand than supply); the model performs a load reduction. In Fig. 7, an example is illustrated for the real-time optimisation. In this figure, the blue bars represent the demand reduction requests/fulfilment and the red bars represent the demand increase requests/fulfilment respectively.

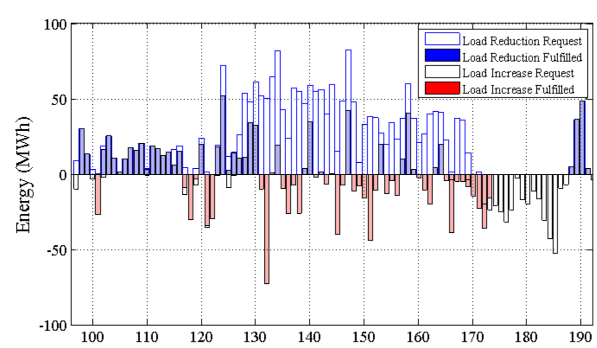

Fig. 7. Example of the real-time optimisation

IV. SCENARIO STUDY

Three scenarios were developed to show the potential economic benefits of residential customers in the Netherlands. During this scenario study it is assumed that a percentage of the Dutch households are fitted with the required control and communication infrastructure to allow for direct load control and communication between the aggregator and the households. Furthermore, a perfect prediction of APX day-ahead spot prices is assumed while the TSO imbalance requests are assumed to become available on real-time. The developed simulation scenarios are the following:

I. Aggregator participates only in the day-ahead market.
II. Aggregator participates in the day-ahead spot and balancing markets.
III. Aggregator participates only in the balancing market.

A. (Historical) Price Volatility

The electricity market experiences price volatility for various reasons. Historical price volatility is a measure of price fluctuations observed over a time period (e.g. hourly, daily, weekly or yearly). According to [10], price volatility depends on a large number of parameters such as: fuel prices, availability of generating units, demand elasticity and variations, network congestions etc. In [9], it is stated that most price volatility analyses are based on the definitions of the standard deviation of logarithmic or arithmetic returns. The logarithmic return over a time period h is defined in [9] as follow:

$$u_{i,h} = \ln\left(\frac{p_i}{p_{i-h}}\right) \quad (1)$$

Where p_i is the spot price at time i. Historical price volatility is defined as σ (standard deviation) of returns [7], [8] and [9]:

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{N}(u_i,h-\overline{u_j})^2}{N-1}} \quad (2)$$

Where N is 24 hours, $u_{i,h}$ is the logarithmic return over the time period h at hour i and $\bar{u}$ is the mean value of the logarithmic returns at certain day j. Fig. 8 depicts historical price volatility of the APX day-ahead market in the year 2010. In the first quartile of 2010 the market experienced two extremely volatile days, while the most volatile day in 2010 was on the 10th of January. During simulation studies and specifically for *Scenario I*, cost reduction figures per household per day are attributed to specific days (i.e. average, most and least volatile day), and those are accompanied by daily price volatility values to provide a reference between the potential economic benefits and price volatility levels.

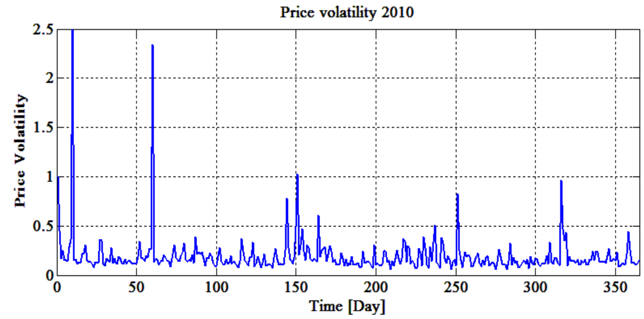

Fig. 8. Daily historical price volatility of the APX day-ahead market in 2010.

B. Scenario I

In this scenario the effect of an aggregator participating in the day-ahead market is simulated. Initially, the analysis includes an investigation of the development of day-ahead prices over the years from 2005 to 2010. When the input of the model is the day of each year characterised by an average price volatility, simulation results indicate that the cost reduction, compared to business as usual (without load control), is in the range of 4% to 8%. This corresponds to a cost reduction in the range of €0.02 to €0.047 per household on a daily base, and the results are presented in the second column of table III.

TABLE III
SCENARIO I: COST REDUCTION PER HOUSEHOLD AND PER DAY

Year	Average day	Most volatile day	Least volatile day
	Cost reduction (c€) / Price volatility σ	Cost reduction (c€) / Price volatility σ	Cost reduction (c€) / Price volatility σ
2010	2.0 / 0.12	3.4/2.51	1.3/0.06
2009	2.4 / 0.17	3.9/7.92	1.1/0.09
2008	3.9 / 0.16	6.1/2.22	2.6/0.07
2007	3.4 / 0.21	4.3/2.15	1.2/0.10
2006	4.7 / 0.21	4.9/2.13	2.0/0.09
2005	4.6 / 0.19	3.3/2.21	1.1/0.08

Additionally, the model is run for the most and least volatile days of the year and the outcome is shown in column three and four of table III. In the case of the most volatile days, the cost savings are in the range of €0.033 to €0.061. In the case of the least volatile days, the cost savings are between €0.011 and €0.026. When examining the effect of price volatility on the cost savings, simulation results shows that the relationship between price volatility and cost savings is not straightforward. Furthermore, the energy increase and reduction which is given as input in the model relates respectively to load reduction and load increase on the day-ahead APX and balancing markets.

C. Scenario II

This scenario investigates the potential cost savings of an aggregator that operates the flexible residential loads in both the day-ahead spot and balancing markets. The considered days for simulation are those days from 2005 to 2010 that are characterised by average price volatility in the day-ahead market.

Extrapolating the results presented in Table IV, over the period of one year, the annual cost savings per household are in the range of €10 - €25. In [15], the authors estimate that hardware and installation costs of the ICT infrastructure for load shifting potential are in the order of €100 per household. This indicates that residential demand response can be cost-effective on the long term but it might require regulatory reform and policy support on the short term.

TABLE IV
SCENARIO II: COST REDUCTION PER HOUSEHOLD PER DAY

Year	Cost reduction (c€)	Energy increase fulfilled	Energy reduction fulfilled
2010	3.1	4.5%	18.2%
2009	4.5	8.2%	22.2%
2008	4.9	3.7%	1.6%
2007	5.2	1.8%	26.8%
2006	6.8	20.9%	20.8%
2005	5.6	4.8%	23.1%

In table IV, it can be seen that the amount of fulfilled requests for energy increase for balancing purposes is relatively small compared to fulfilled energy reduction, especially for the selected days from 2005, 2007, 2009 and 2010. The relatively low percentage of the fulfilled requests for energy increase originates from the fact that the aggregator participates in both spot and balancing markets and most of the resources have already been committed to the day-ahead optimisation. Note that after participation in both markets the cost savings are increased with minimum increase of 22% in 2005 and maximum of 88% in 2009.

TABLE V
SCENARIO III: COST REDUCTION PER HOUSEHOLD PER DAY

Year	Cost reduction (c€)	Energy increase fulfilled (%)	Energy reduction fulfilled (%)
2010	2.4	16.9%	56.1%
2009	2.6	19.2%	61.5%
2008	4.1	21.6%	54.5%
2007	2.2	15.8%	53.8%
2006	3.5	15.7%	54.5%
2005	3.3	11.8%	57.1%

D. *Scenario III*

In this scenario the benefits of the aggregator participating only on the balancing market is assessed. According to the results presented in table V, it can be observed that the fulfilled load increase is around 20% while the fulfilled load reduction is around 50%. The first reason for these results originates from the fact that during the simulated days, the amount of requests for negative balancing capacity where larger compared to those for positive balancing capacity. The second reason relates to the control strategy, since the potential for load increase actions are related to the load reduction actions that were taken in the past.

V. CONCLUSIONS

In this paper the working procedure of an envisioned market party, so-called the aggregator has been simulated. The aggregator may contract large amounts of residential customers and then coordinate them under different objectives (i.e. economic optimisation based on predicted day-ahead prices and the provision of balancing energy). During the effort to quantify potential economic benefits of future concepts, such as residential demand response, some assumptions had to be made. Historical market data were utilised as input, but still there is high uncertainty of how future prices will evolve, especially for electricity which is currently traded in increasingly deregulated environments. Furthermore, the optimal number of households that should be fitted within the control scheme depends on each particular application, and the objectives of the aggregator. The aim of this paper is to provide an insight into the possibilities and the challenges offered by an energy management system, which is able to modify the load profile of a group of households (i.e. based on information related to the day-ahead spot prices and the imbalance prices). Simulation results indicate that price volatility will provide economic benefits for residential demand response, because in principle the aggregator will act as an opportunity seeker trying to take advantage of price differences. From the analysis of the scenarios it is concluded that increased price volatility will result in more energy cost savings per household. However, at the same time, an increased participation of the demand side in electricity markets will eventually influence prices and it is expected that it will result to reduced price volatility. Overall, simulation results show that the potential economic benefits of residential demand response on the Dutch electricity markets are relatively low in a per household basis, but not negligible for the business case of the aggregator.

Furthermore, in this work, the potential cost savings for residential customers are calculated by using the historical day-ahead clearing prices as reference values. However, by taking into account the differences between retailing tariffs for residential markets and clearing prices in forward, future and spot markets, then there is an additional margin for the aggregator to further maximise profits.

The incorporation of intermittent and less predictable generation complicates the operation and planning of power systems. In an electrical power system where large scale energy storage solutions are not available, residential demand response can become an interesting business case for new entities in the energy market, provided that constructive regulating reforms are implemented to allow the active participation of the demand side in electricity markets.

VI. Acknowledgment

The authors acknowledge APX for the provision of historical market data.

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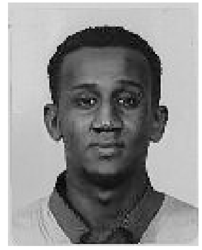
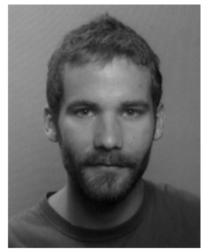
VIII. Biographies



Ahmed Abdisalaam was born in Mogadishu (Somalia) in 1985. He studied Mechanical Engineering at Polytechnic University in Tilburg/Breda (2007). In November 2011 he received his M.Sc. degree in Sustainable Energy Technology from Eindhoven University of Technology. Present he is working for GDF SUEZ Energy, The Netherlands. His research interest relates to energy management, bio-energy and the potential energy innovations in Africa.



Ioannis Lampropoulos (S'10) received the Dipl. Ing. degree from the department of Electrical & Computer Engineering, National Technical University of Athens in 2006. In 2009, he received the M.Sc. degree in Sustainable Energy Technology from Delft University of Technology. From February 2010 he is carrying out research at the group of Electrical Energy Systems, Eindhoven University of Technology. His research interests are in the areas of planning and operation of power systems, demand side management, decentralised generation and sustainable development**.**

Jasper Frunt obtained his B. degree in electrical engineering in 2003 from the University of Professional Education in 's-Hertogenbosch. In 2006 he received his M.Sc. degree in sustainable energy technology from Eindhoven University of Technology. For his graduation projects he worked with KEMA N.V. and TenneT TSO BV. (Dutch Transmission System Operator) respectively. In 2011 he obtained a Ph.D. degree with his thesis Analysis of Balancing Requirements in Future Sustainable and Reliable Power Systems. Currently he is working as a technical specialist in power balancing and balancing markets at KEMA N.V. in the Netherlands.

Geert P.J. Verbong is Associate Professor in the History of Technology at the Department of Technology Management at Eindhoven University of Technology. He studied physical engineering at Eindhoven University of Technology (1981) and did his Ph.D. on innovations in Textile Printing and Dyeing in the Netherlands, at TU/e (1988). He is the coordinator of the research program 'Transition and transition paths: the road to a sustainable energy system', funded in a NWO/Novem framework; this program is set up to encourage the cooperation between natural and social scientists (beta-gamma) in the field of energy research.

Wil L. Kling (M'95) received his M.Sc. degree in electrical engineering from the Technical University of Eindhoven in 1978. Since 1993 he has been a (part-time) professor in the Department of Electrical Engineering at Delft University of Technology, in the field of Power Systems Engineering. Since 2008, he is a full-time professor at Eindhoven University of Technology where he is leading research programmes on distributed generation, integration of wind power, network concepts and reliability. Prof. Kling is involved in scientific organisations such as CIGRE and the IEEE. As Netherlands' representative, he is a member of CIGRE Study Committee C6 Distribution Systems and Dispersed Generation, and the Administrative Council of CIGRE.