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Data Analytics for Household Energy Consumption

DAHEC

Executive summary

The changing scenario in the residential energy market requires the energetic players of today to adopt innovative approaches for business to be still part of the competition tomorrow. Novel market opportunities need to be tested and the on-field validation can be prohibitive due to cost, time constraints and complexity of pilot projects.

DAHEC (Data Analytics for Household Energy Consumption) project aims to analyse and validate novel market opportunities through virtual pilot projects fed with synthetic but realistic disaggregated consumption data, overcoming the obstacles of real pilot projects. The synthetic data are outputs of a simulator of households' energy consumption, ad-hoc implemented during the project. The innovative path developed by DAHEC team makes the assessment of market opportunities feasible. Thanks to virtual pilot projects, Smart Bills for White Certificates as well as price-based and incentive-based Demand Response are evaluated to estimate stakeholders' benefits.

Key Words Energy market, Smart Bills, Demand Response, Simulator, Data analytics.

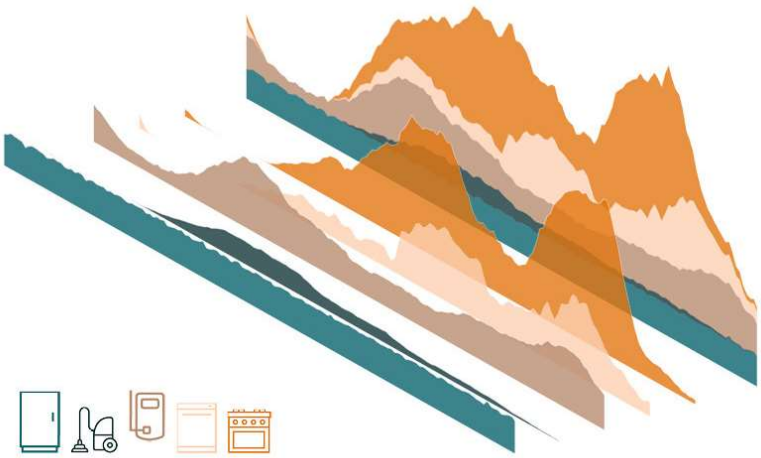

Figure 1: Disaggregated energy consumption data

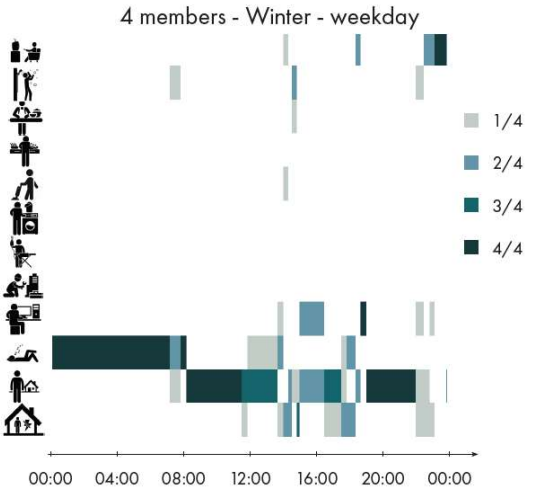

Figure 2: Example of behavioural simulation.
Daily behaviour of a 4-member family.

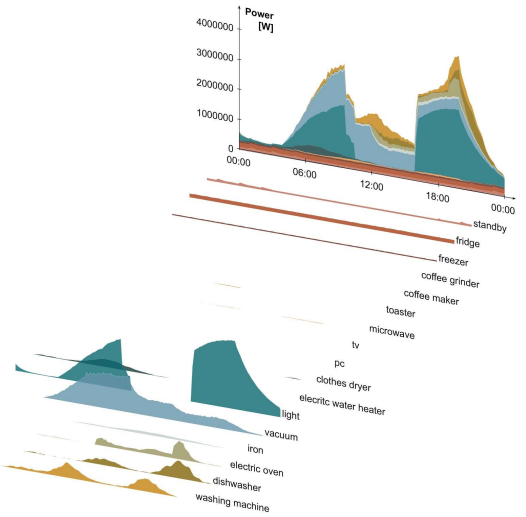

Figure 3: Disaggregated consumption profile.
Simulation of consumption profiles of 10 thousands families.

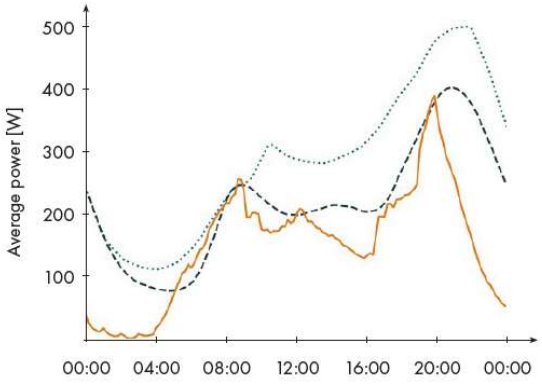

Figure 4: System validation.
DAHEC average power profile (orange) is compared with other studies about real households' energy consumption (blue).

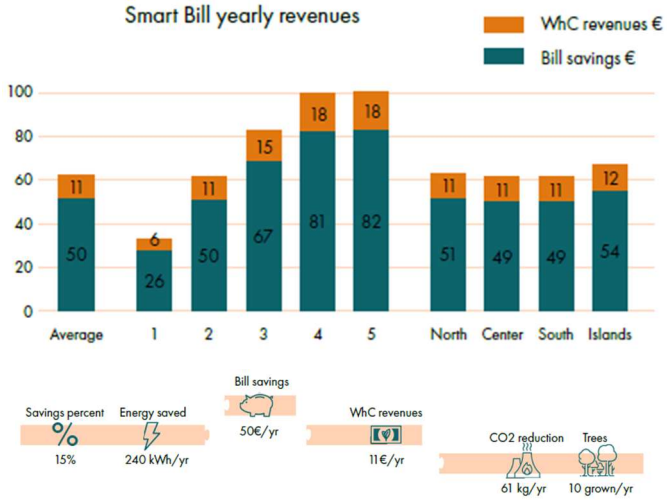

Figure 5: Output of Smart Bills virtual pilot project.
Final customers' savings and benefits for an average family.

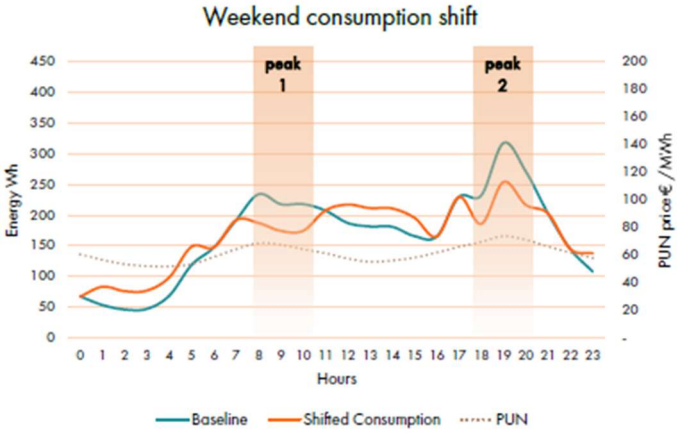

Figure 6: Design of price-based Demand Response virtual pilot project.

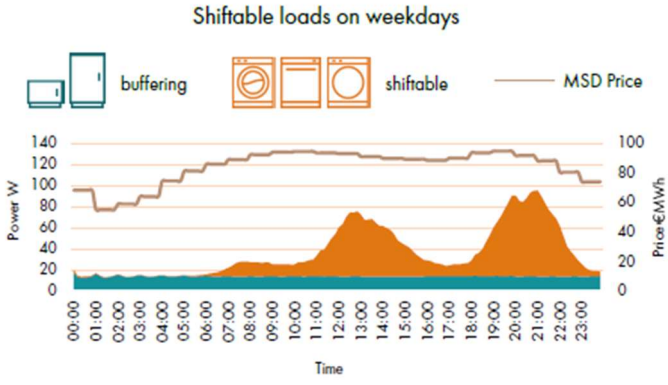

Figure 7: Preliminary step of incentive-based Demand Response virtual pilot project.
Selection of the shiftable load for the average simulated family.

Project description written by the Principal Academic Tutor

DAHEC project aims at designing a feasible and ready to use solution to evaluate market opportunities in the energy sector. In this context, it aims at developing a software tool for Big Data analytics based on energy load profiles.

The project starts from a market analysis that aims at identifying new data-driven business opportunities by exploiting fine-grained information about the appliances' energy consumption. From such analysis a set of stakeholders' requirements arises, which underlines the necessity of the design and development of a simulator of residential energy consumption to evaluate the impact of market opportunities previously identified.

The final outputs of the project are:

1. A set of requirements coming from an in-depth market analysis aiming at profiling the end-users based on their household energy consumption patterns.
2. A novel system architecture for Big Data Analytics to simulate end-users energy consumption profiles.
3. New market opportunities to foster new services in the electrical marketplace to be tested and validated in a virtual environment by exploiting the end-users energy consumption profiles.

Different stakeholders can take advantages of the results of this project:

- Energy companies can benefit from the output of the project to support their decision making, as a tool to evaluate new market opportunities, optimize planning activities of smart grid or support operational management. In addition, Energy utilities could profile consumers and offer personalized pricing policies.
- Researchers can take advantage of these results for different research activities (e.g. compensate lack of consumption profile data and perform behavioural and energy studies of the population).
- Policy makers can test novel services and control strategies for smart grid management and load balancing.

Team description by skill

DAHEC team is composed of two subgroups: the first one focused on the market analysis, the second one worked on the implementation of a households' energy consumption simulator.

Milica Vojinovic ad Marco Teodori were in charge of the market analysis. Milica Vojinovic applied her knowledge in Management Engineering to the analysis of the market context and validation of the opportunities. Marco Teodori provided meaningful insights with his background as an Energy Engineer and supported the identification of viable market opportunities.

Nicola Barletta, Ilaria Botticelli and Luca Colomba exploited their Computer Engineering and Data Science skills in the design and development of the software components required by the project. Alessandro Barilli and Celeste Principi, as Mathematical Engineers, provided fundamental support with their competencies in statistics and data modelling. Celeste Principi, as team leader, also supervised the coordination of the subgroups to achieve a cohesive result and cared of deadlines and deliveries.

Goal

Energy market in the residential sector is evolving due to new European regulations and a stronger awareness towards sustainability. Novel market opportunities to address these issues have been investigated and energy players are considering some new business models. DAHEC project focuses on the residential energy sector, exploiting disaggregated consumption data, in order to identify innovative yet feasible market opportunities to tackle the change.

The feasibility and profitability of market opportunities need to be assessed through pilot projects on a large scale. Actually, implementing pilot projects is not trivial: they require costly investment, they need to follow strict regulations

and people's involvement implies privacy issues. Moreover, they can take time to be performed and in such a dynamic market, time cannot be wasted.

In this context, DAHEC (Data Analytics for Household Energy Consumption) project aims to overcome the implementation impasse through virtual pilot projects fed with disaggregated consumption data. These data are generated by a simulator implemented ad hoc during the project to recreate a huge virtual population that resembles Italian families and to describe the energy consumption at device usage level during a potentially unlimited time span.

Understanding the problem

The energy market in the residential sector has been changing in the last few years and it is expected to undergo a stronger change in the next future. The well-known higher penetration of renewable energies is challenging the energy producers and the electrical grid itself will require a disruptive innovation. At the same time, the market regulation is promoting the final part of the liberalization process: in Italy the market is expected to become totally free in 2020, ending the Service of Greater Protection.

In order to keep its competitiveness, a player in the energetic market will be required to deeply change its approach and business. Novel market opportunities have been investigated and some business models are already "on the table" of energy players.

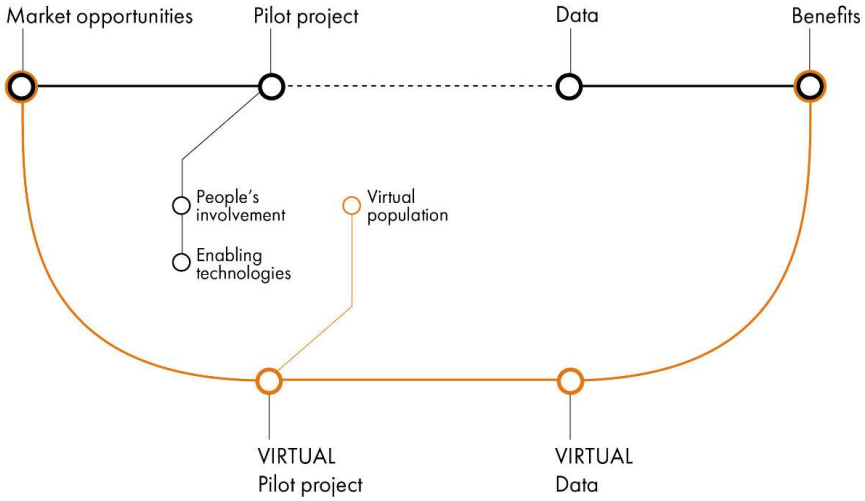

Figure 8: DAHEC path, from the canonical validation journey to an innovative simulative approach

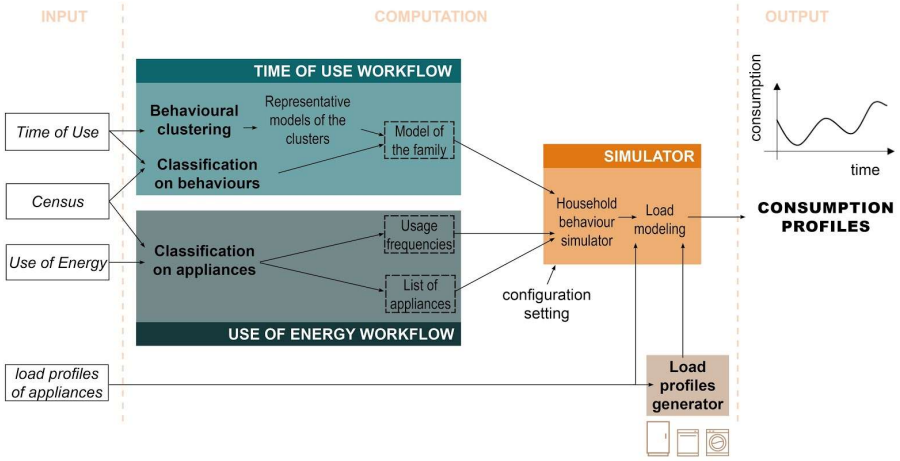

Figure 9: System architecture of the simulator

Exploring the opportunities

Implementing new strategies in the energy market has its barriers: the biggest one is that new market opportunities must be tested through pilot projects involving lots of households. The technologies to collect disaggregated households' consumption data are mature but still at their early stage of diffusion, so the very large scale required to have a substantial output from the pilot projects can be difficult to obtain because they require costly investment and involve privacy issues.

Generating a solution

DAHEC project aims to analyse and validate novel market opportunities through virtual pilot projects, overcoming the already mentioned obstacles of real ones (see Figure 8: DAHEC path). Virtual pilot projects are fed with disaggregated consumption data generated by DAHEC simulator, which is implemented to recreate a huge virtual population and to describe its energetic consumption at device usage level by modelling heterogeneous families' behaviours, ownership and usage of each type of appliance.

Assuming the availability of the disaggregated household consumption data, DAHEC project identifies several market opportunities and evaluates them based on the market analysis and direct contacts with companies from the energy sector. The identified market opportunities are: Demand Response, Smart Bills for White Certificates, energy saving virtual assistant, Energy Service Companies (ESCos) for energy efficiency, Feedback on appliance performance, Property monitoring based on appliance usage and Data trading with third parties. The selection process is performed based on insights obtained during the Utility day, the most important event about Italian energy industry and its output is the selection of two business opportunities that are mutually compatible: Smart Bills for White Certificates and Demand Response. The Smart Bill opportunity foresees that the electricity retailers provide a detailed bill, enhanced by the appliances consumption, which results in energy savings with twofold benefits: lower bill for customers and revenues from Energy Efficiency Certificates (White Certificates) for energy utilities [1]. Demand Response opportunity consists of price-based and incentive-based programs that motivate customers to shift a share of their consumption from the peak demand hours to off-peak periods, for which they receive financial benefits [2].

The selected market opportunities need to be tested for effectiveness through pilot projects. As already mentioned, DAHEC opts for designing virtual pilot projects fed virtual disaggregated consumption data that give details of consumption at device level. Taking inspiration from previous works [3], DAHEC simulator is an unlimited source of disaggregated consumption load curves with a degree of complexity and diversity comparable to that guaranteed by a large-scale pilot project. It considers four datasets as inputs. Three of them are ISTAT datasets: Time of Use (TOU) with data about families' members and their daily diary of activities; Use of Energy (UOE) containing data about electrical appliances; Census, that provides a general overview of the Italian population with information concerning both the household and its members. The fourth input is a collection of load curves of real appliances. The system architecture is composed of three macro-modules (see Figure 9: System architecture of the simulator). The first one, called Time of Use workflow, is focused on modelling families' behaviours. It splits families recorded in TOU in more than a hundred clusters with similar behaviours and it estimates one behavioural model for each of the clusters. Then, given a family of Census dataset, TOU-workflow assigns it to the cluster containing the families that show the most similar features, so that it results to be represented by the model of that cluster. The second macro-module, called Use of Energy workflow, is aimed at predicting appliances' ownership and weekly usage. In this block, classifiers of the presence of appliances in the households and predictors of their usage frequencies are trained over UOE dataset. Then, given a household of Census dataset, it can be characterized by the list of appliances it owns and their weekly usage. The core macro-module of the system is the simulator itself. Given a family of Census dataset, the simulator takes as input the model of family (output of TOU-workflow), the information about presence and usage of appliances (output of UOE-workflow), and load

profiles of appliances. Then, it follows a step-by-step approach: every 10-minutes it simulates the behaviour of the family (see Figure 2: Example of behavioural simulation) and it translates it in terms of appliances usage (e.g. TV is working) or activation (e.g. begin of a washing machine cycle). Finally, appliances usage and activation are turned into consumption profiles exploiting their load profiles, eventually pre-processed by a load profile generator that enriches them with metadata about type of cycle and energy class label.

The simulator is used to feed virtual pilot projects to evaluate the two most promising identified business models: Smart Bill and Demand Response. The pilot projects involve the simulation of disaggregated load curves of a sample of 10000 Italian families to get the overall energy consumption (see Figure 3: Disaggregated consumption profile). An analysis of member-based and geographically based consumption is allowed by simulating a sample of 10000 families with 1, 2, 3, 4 and 5 members and distributed in North, Centre, South and Islands respectively. The resulting load curves are reliable in terms of shape and placement of peaks, since they shows consistency with the previously available studies [4, 5] on real consumption (see Figure 4: System validation). From the pilot projects, the Smart Bill shows convenience for target segment of families with 3 and more members regardless of the geographic distribution starting from 67€ of electricity bill savings for customers and 15€ worth of White Certificates for the service provider (see Figure 5: Output of Smart Bills virtual pilot project). The economic benefits of Demand Response are not convenient within the current market context. The price-based DR (see Figure 6: Design of price-based DR virtual pilot project) creates up to 2% savings on the energy component of the electricity bill, and the incentive-based program (see Figure 7: Preliminary step of incentive-based DR virtual pilot project) brings 9€/year for the average household. The benefits will increase with the higher diffusion of shiftable loads (e.g. heat pumps, electric vehicles and smart appliances) and with the improved split of the overall system efficiency gains.

To the best of our knowledge, DAHEC is the first successful method for testing new market opportunities that can be adopted by energy market actors even before having the totality of data about the evolution of the market.

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