A Novel Research Algorithms and Business Intelligence Tool for Progressive Utility's Portfolio Management in Retail Electricity Markets

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***Abstract*— Progressive electric utilities are gradually digitizing their business in order to be able to efficiently manage their customer portfolio and cope with the increasing competition in the retail market. Thus, advanced S/W tools and platforms are needed, like the Research Algorithms and Business Intelligence Tool (RABIT) proposed in this paper. RABIT provides advanced data analytics services (i.e. advanced search, profilers, recommenders) targeted to the utility's administrative users (e.g. business analysts). In addition, it disposes: i) dynamic and behavioural pricing models linked with various innovative energy programs, and ii) algorithms for the creation and dynamic adaptation of virtual energy communities. RABIT can also automatically analyze exhaustive business/strategy 'what-if' scenarios by running parameterized system-level simulations. Performance evaluation results show that a utility company can exploit RABIT in order to: i) reduce costs for purchasing energy from wholesale market, ii) enhance its end users' welfare, iii) increase its business profits, and iv) increase its portfolio's energy efficiency.**

Keywords*— *data analytics, demand response, digital electric utilities, dynamic pricing, virtual energy communities

I. Introduction

For today's electric utilities and retailers, standing still is not an option as the traditional utility retail business model is under increasing threat. There are three main driving forces paving the way for the digitization of progressive electric utilities, namely: i) regulatory and policy shifts, ii) changing market demand, and iii) technology innovation [1]. As shown in Fig. 1, progressive electric utilities handle large volumes of data, which are often complex in structure and are produced in real-time [2]. These data sources can be categorized as: i) energy related, ii) behavioral, iii) based on online social network, and iv) other data sources. The 1st step is to gather, store and easily retrieve these datasets using a well-designed database. Then, data analytics tools are needed in order to unveil the potential added value out of these structured datasets. The 3rd step is to combine data analytics results with specific Key Performance Indicators (KPIs) in order to quantify research algorithms' results and assess their business impact. The final step is to automate the business analytics process and connect it with the real-time business operation.

In this paper, we propose a novel Research Algorithms and Business Intelligence Tool (RABIT) developed in the context of H2020 SOCIALENERGY project [3] that:

- Automatically creates innovative energy programs (or else pricing schemes) and runs exhaustive "what-if" scenarios to precisely quantify important KPIs for utility's business, such as energy cost reduction, users' welfare, business profits, aggregated energy consumption reduction, etc.
- Creates and dynamically adapts Virtual Energy Communities (VECs) based on multiple parameters, such as energy data related analytics, behavior data related analytics, social network data analytics, etc.
- Offers advanced search, profiling and recommendation services to the utility user (i.e. administrator or else business analyst) facilitating the establishment of efficient communication channels with the end users and VECs for advanced quality of service (QoS), digital marketing, and e-commerce purposes.

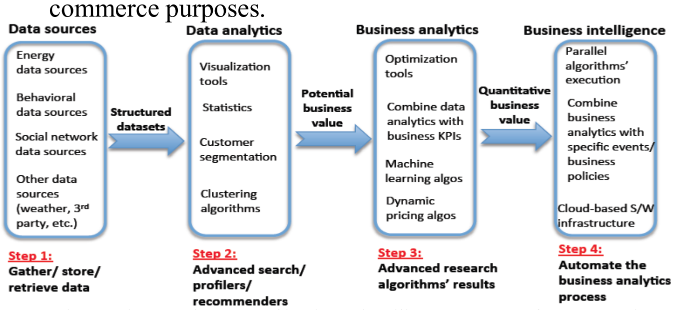

Fig. 1. The 4 main steps of business intelligence process for progressive electric utilities

II. SOCIALENERGY System Architecture, Business Model and RABIT's Value Proposition

A. SOCIALENERGY system architecture

Fig. 2 presents a high-level architecture design of SOCIALENERGY system, which comprises of five S/W components (apart from RABIT), namely:

1) The core Green Social Response Network (GSRN) or else SOCIALENERGY's real world, which is a S/W platform that provides a user-friendly interface to the end user to navigate through all other subsystems via a single sign-in authentication process.

2) SOCIALENERGY GAME or else virtual world, which provides both fun and educational gameplay to the end user.

3) Learning Content Management System (LCMS), where the end user is formally educated about best practices on energy efficiency.

4) Virtual Marketplace, where various market stakeholders can dispose their energy efficient products/services, while end users can enjoy beneficial offers and discounts.

5) Meter Data Management System (MDMS), which is the central database, where all types of data (energy, behavioral, social, etc.) are gathered, stored and efficiently retrieved.

Finally, RABIT (cf. red-font-outlined area in fig. 2) provides all data analytics and business intelligence services to SOCIALENERGY platform. RABIT's role is critical towards making SOCIALENERGY platform competitive enough in the retail electricity market. More details about SOCIALENERGY S/W platform's functionalities can be found in [3] [4].

B. SOCIALENERGY Business Model and RABIT's value proposition

SOCIALENERGY S/W platform follows a platform-based, multi-sided and customer-centric business modeling approach. It enables online social network effects and can absorb exponential digital growth mechanisms. It also follows a modular-by-design approach through the development of multiple Application Programming Interfaces (APIs) enabling open, combinatorial and incremental innovation. This approach provides business flexibility for SOCIALENERGY to be commercialized taking into consideration the diversified needs of today's progressive electric utilities.

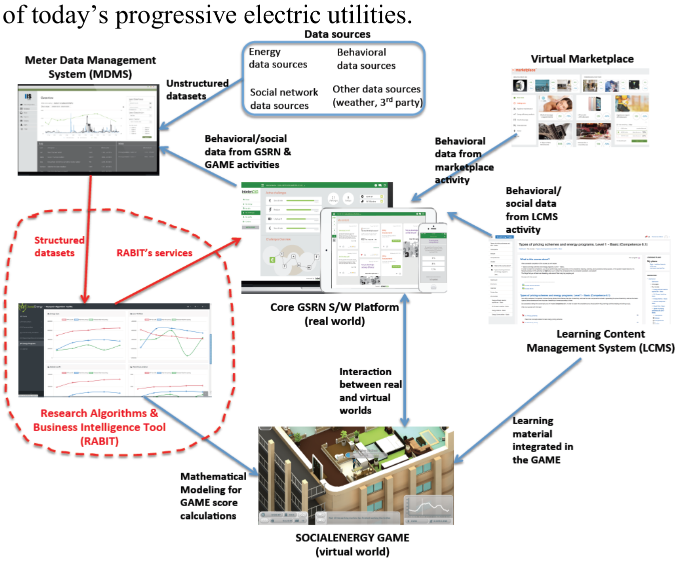

Fig. 2. SOCIALENERGY's System Architecture (Modular-By-Design)

In this paper, we focus on RABIT's value proposition. By using RABIT, a progressive electric utility's business analyst can closely monitor the business process and analyze all ongoing business-related data in an intelligent way towards defining the company's strategy and policies in the short-, medium- and even longer-term future. Thus, the utility company is able to understand the behavioural trends of its customers in order to provide high QoS to them, minimizing the churn rate and increasing the portfolio's size. RABIT can also automatically analyze exhaustive business/strategy 'what-if' scenarios by running parameterized system-level simulations aiming at improving critical KPIs such as: i) reduce costs from purchasing energy from wholesale market, ii) enhance end users' welfare, iii) increase business profits, and iv) increase portfolio's energy efficiency.

Moreover, RABIT is a user-friendly administrative tool for the building up and online governance of VECs. Finally, RABIT includes advanced algorithms that are able to mine deeply into the available datasets and provide "clusterings" of users, who have similar energy consumption/ behavioural habits, interests, needs, etc. Based on these automated "clustering" results, the admin user is able to apply a common business policy to a targeted subset of the utility's portfolio in a way that minimizes operational expenditures (OPEX) and provides high QoS to the end users.

III. RABIT'S FUNCTIONALITIES AND SERVICES

A. System-level simulations before the release of new energy programs in the retail market

Before releasing a new Energy Program (EP) in the retail market, an electric utility company should perform exhaustive system-level simulations in order to ensure that specific KPIs related to the utility's business policies are met. As shown in Fig. 3, the utility company purchases energy from the wholesale market at a time- and volume-variant cost $G\ (x,t)$ in order to satisfy the demand of its customer portfolio. End users can provide flexibility by curtailing or shifting their loads to off-peak hours in response to dynamic price signals published by the utility. This aggregated flexibility creates a considerable cost reduction ΔG, which can be beneficial to both the consumers (by reducing their bills) and the utility (by creating more business profits). In more detail, by modifying the aggregated Energy Consumption Curve (ECC) according to G, the *System's Energy Cost (SEC)* is reduced, the *Aggregated Users' Welfare (AUW)* is increased, while electricity bill reductions are analogous to each flexible consumer's contribution in the reduction of SEC. This last *fairness* KPI metric is a strong incentivizer for behavioral change, in contrast to traditional Real Time Pricing (RTP) programs, where there is a single price per energy unit per timeslot for all end users, and thus inflexible users' electricity bills are also unfairly reduced without having contributed to the SEC reduction that other flexible users have brought about.

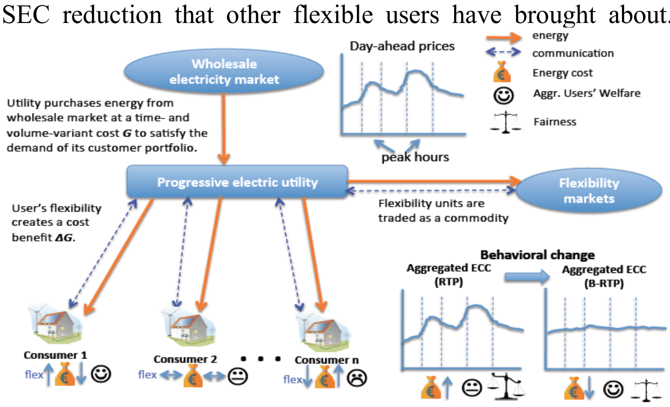

Fig. 3. Novel Energy Programs' Modeling and related KPIs [6]

In RABIT, the system-level simulations can be fully parameterized. There are 4 main steps to customize a specific simulation scenario. Firstly, the aggregated ECC should be selected, which requires specifying the: i) set of end consumers, ii) start and end times of the simulation, iii) time interval (ranging from 5 minutes to one day), and iv) ECC type (e.g. peak/off-peak hours, weekend vs. weekdays, etc.). The second step is to define the input parameters for the SEC model (i.e.

energy cost and profit margin-related parameters). Then, the end user model parameters are defined (i.e. flexibility curves and requirements), followed by the energy program parameters. Currently, RABIT supports all traditional energy pricing schemes, namely fixed, Time-of-Use and Real Time Pricing (*RTP*). Moreover, novel pricing schemes are supported, namely RTP with a demand response (DR) mechanism, Personalized RTP (*P-RTP*) schemes and Community RTP (*C-RTP*) schemes. The P-RTP model proposed in [5] assumes only load cuts and a budget-balanced business scenario. Similarly, [6] assumes a P-RTP scheme, but also models load shifts and utility's participation in flexibility markets for profit maximization. Finally, the basic C-RTP model is presented in [7], where the end users are clustered into VECs according to a similarity index of their ECCs, flexibility and social interactions.

B. Management of multi-parametric VECs

By utilizing Energy Data Analytics (EDA), Online Social Network Analytics (OSNA) and Behavioral Data Analytics (BDA) from the SOCIALENERGY S/W platform, the utility's business operations can be automated and become more intelligent. As illustrated in Fig. 4, RABIT's VEC creation algorithms can be fully parameterized according to a wide range of utility's business objectives. For example, end users with similar EDA patterns may participate in a common C-RTP program in order to achieve better energy efficiency results (cf. section IV.B). Furthermore, if these users are friends in SOCIALENERGY's Green Social Response Network (GSRN), they could collaboratively achieve even better aggregated flexibility due to the social/peer pressure that VEC members induce to each other [7]. Finally, through BDA, end users who have similar activity patterns within the various SOCIALENERGY subsystems (i.e. GSRN, GAME, LCMS) are clustered together to experience more personalized services and offers by SOCIALENERGY system. For instance, an end user who has achieved a high GAME and/or LCMS score during the last months may be selected as a VEC leader being responsible for creating new educational material in LCMS and thus act as "influencer" within the GSRN.

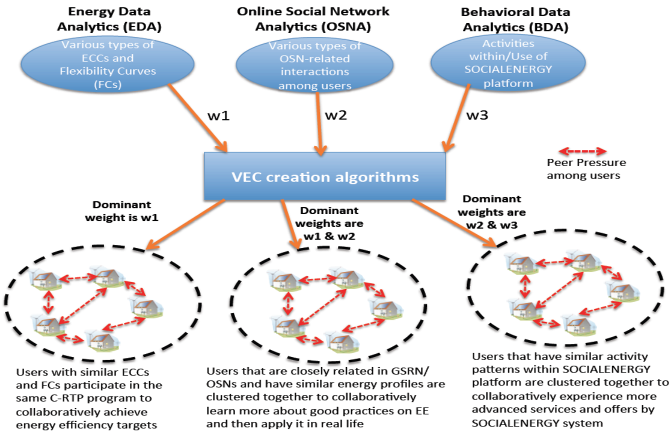

Fig. 4. Multi-parametric VEC creation and dynamic adaptation algorithms [4]

Machine learning algorithms for VEC creation from the following works have been integrated in RABIT so far: i) [8] proposes spectral clustering and genetic algorithms that put together users, who have the minimum deviation between their forecast and real consumption patterns in order to minimize the imbalances of the utility's portfolio, ii) [9] creates VECs in order to find the set of prosumers whose aggregated prosumption profile can best fit a given target pattern requested by a market actor (e.g. TSO/DSO), who requests flexibility services, and iii) [7] demonstrates that the joint utilization of both EDA and OSNA can further lower the SEC compared to the case in which only EDA or OSNA are utilized.

C. Advanced search, profiling and recommendation services

VEC creation is a dynamic process closely inter-related with RABIT's advanced search, profiling and recommendation services. Initially, a business objective should be defined by the administrative user. Then, all energy consumers that meet the specific business criteria are selected and subsequently several VECs are created using one of the algorithms described above. Significant changes in the users' profiling information may incur a need for VECs' structure adaptation (i.e. dynamic VEC adaptation process). Once the updated VECs have been created, the final step is to automate the recommendation process by creating specific rules for each business objective case and then send the required messages to end users (i.e. VEC members). End users are then able to see the recommendation messages in their GSRN web interface.

IV. Indicative Performance Evaluation Results

The source code of RABIT's software is publicly available in SOCIALENERGY's Github area. [10] provides a detailed user manual for researchers and developers who want to download, install and run online simulations in RABIT as well as more technical details for simulation setup.

A. Comparison among various energy programs

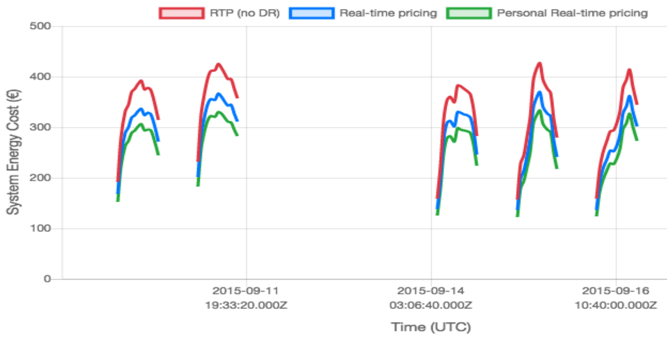

Fig. 5. P-RTP achieves System's Energy Cost (SEC) reduction

For setting up a system-level simulation, we define the input parameters as described in section III.A. We assume: i) a mix of 100 real residential and 10 commercial consumers in Athens, Greece, ii) one week duration between Thursday 10/9/2015 and Wednesday 16/9/2015, iii) 1-hour time interval measurements from real smart meters, iv) energy data only for weekdays (i.e. Monday-Friday) only between 08:00 and 20:00, v) energy cost that grows quadratically with constant parameter equal to 0.2, vi) profit margin parameter equal to 0.2 (i.e. 20% of SEC reduction is allocated to business profit and the residual 80% is allocated to users' bill reductions), vii) mix of high (20%), medium (50%) and low (30%) flexibility consumers (i.e. high flexibility means high eagerness to consume less in response to higher prices). We then simulate and compare 3 EPs, namely: a) RTP with no DR mechanism (red lines), b) DR-enabled RTP (blue lines), and c) P-RTP (green lines). P-RTP simulates the situation, in which each end user is compensated based on her individual contribution in SEC reduction (i.e. there is a different price *p(t,i)* not only per timeslot *t* like classic RTP but also per end user *i*).

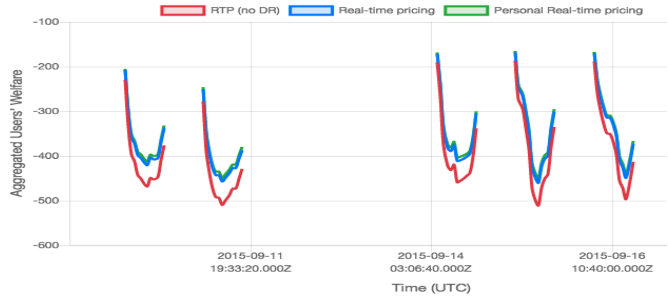

Fig. 6. P-RTP does not affect Aggregated Users' Welfare (AUW)

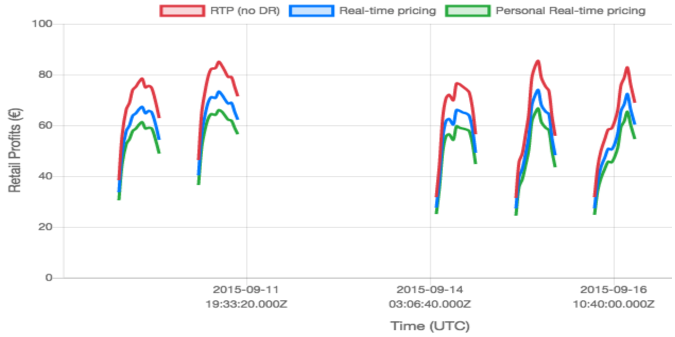

Fig. 7. P-RTP reduces retail profits, but overall business profits (i.e. SEC reduction minus retail profit reduction) are considerably increased

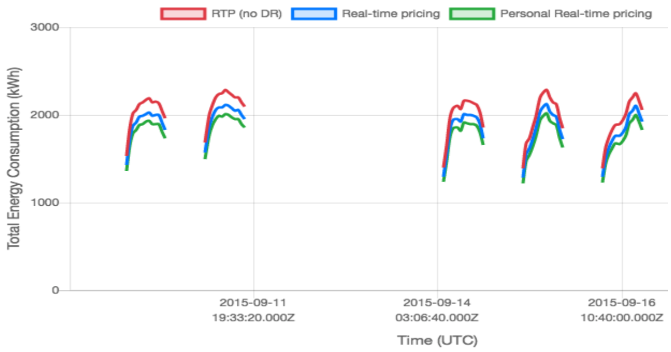

Fig. 8. P-RTP achieves aggregated energy consumption's reduction

Fig. 5 shows that SEC (or else the cost for purchasing energy from wholesale market) can be reduced by ~20%, if the utility adopts a DR-enabled RTP program. We can also observe that P-RTP curve (green line) is always under the DR-enabled RTP one (blue curve), which means that the proposed novel P-RTP program can further reduce SEC by another 7% (on average) compared to state-of-the-art RTP. As shown in Fig. 6, the AUW, which is defined as the aggregated users' satisfaction minus their total electricity bills, is enhanced in DR-enabled RTP and P-RTP cases. Green and blue lines almost coincide, which means that P-RTP can further reduce SEC without deteriorating AUW.

Fig. 7 shows that company's profits in the retail market are considerably decreased following a similar pattern with SEC reduction (cf. fig. 5). This is easily explained by the fact that behavioral changes incurred by the DR process (i.e. energy cuts), also imply a decreased energy consumption, which decreases revenues. However, the utility is interested in the overall business profits defined as the SEC reduction minus retail profit reduction. Combining Figs. 5 and 7 results, we observe that SEC reduction is much greater than the retail profit reduction, resulting thus in a considerable OPEX reduction ranging from approximately 12% up to 25%.
Utilities are obliged by energy efficiency related regulations to satisfy respective targets such as the reduction of their energy sales by a factor of 1.5-2% per year [1]. They can even get subsidies if they achieve more reductions (e.g. via white/green certificates) or receive stiff penalties if they do not manage to incur the required behavioral changes to their customer portfolio. Fig. 8 shows that the aggregated energy consumption can be reduced by an average 13% in the P-RTP case. This energy efficiency result entails both increased utility's business profits and decreased end users' electricity bills. Via the control of the profit margin parameter (π), the company can choose the exact way that SEC reduction will be allocated. In particular, low value of 'π' means less business profits, but increased competitiveness due to more attractive P-RTP bills. RABIT disposes a 'γ' parameter ($0<\gamma<1$), which models hybrid P-RTP programs as described in [6]. In this paper, a purely P-RTP program was simulated (i.e. $\gamma=1$), while a γ value closer to 0 would simulate a program closer to DR-enabled RTP.

B. VEC creation according to energy consumption pattern and recommendation of suitable VEC and C-RTP program

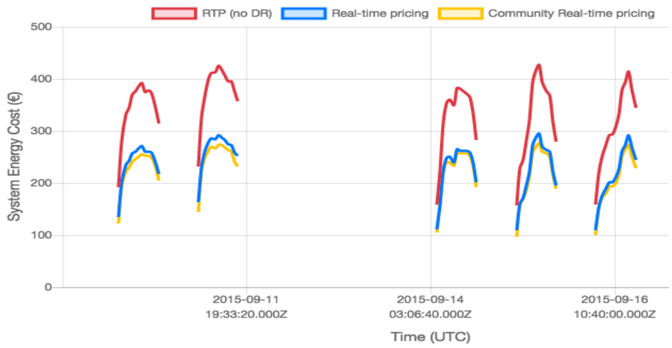

Fig. 9. C-RTP achieves System's Energy Cost (SEC) reduction

Similarly to Fig. 5, Fig. 9 presents SEC reduction results for the proposed C-RTP program. The same simulation parameters were used except for the set of consumers chosen. In particular, a total of 50 commercial only users have been used in order to have meaningful "clusterings". The number of clusters is also an input parameter and it has been set equal to 3 in these experiments. VECs have been created taking into consideration the social interactions of the end users. For instance, the members of these VECs may belong to a single owner or else VEC leader, who wants to apply a single C-RTP program to all of his/her commercial buildings in order to lower the aggregated electricity bill (e.g. supermarkets, hotels, university campus buildings, etc.).

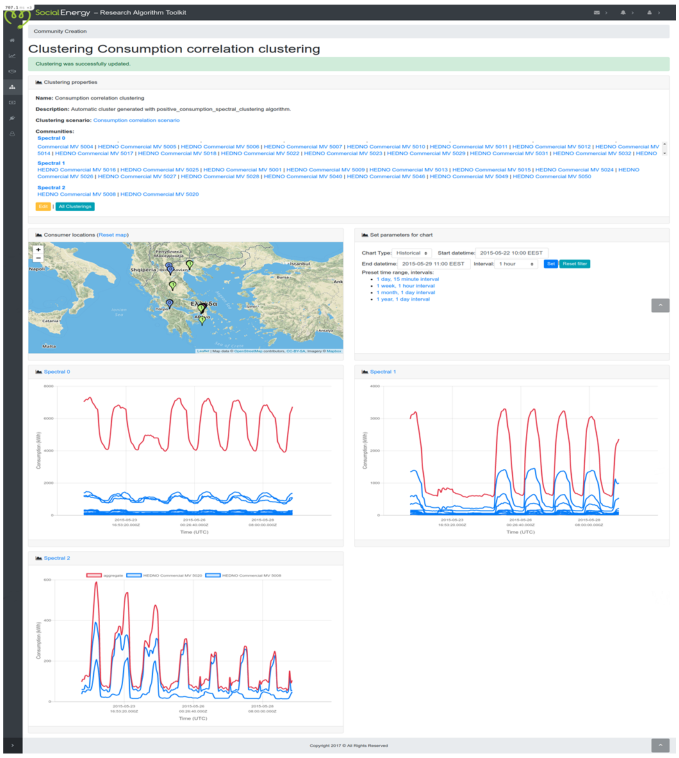

Fig. 10. Indicative clustering based on positive correlation of ECC patterns

In Fig. 10, we can see a different clustering that is based on the correlations of the consumption profiles (i.e. ECCs). Specifically, we can see how the above consumers have been classified into three clusters, where the spectral clustering algorithm [8] was used for creating the VECs. The algorithm uses as input a "distance" between each pair of nodes, which in our case was defined as the cross-correlation in the consumption between in each pair. Fig. 10 depicts at the top the list of consumers in each VEC, and in the middle, we can see their locations on the map, with each VEC being marked with a different color. Finally, in the lower part of Fig. 10, we can see the aggregated ECCs (red lines), as well as the individual curves for each consumer (blue lines). The similarity in the ECC pattern of each community is evident in the figure. For example, VEC "Spectral 1" contains consumers with lower consumption on Sundays, "Spectral 2" contains consumers with low consumption on the whole weekend, and "Spectral 3" contains the remaining consumers that don't fit in any of the two previous groups. For each VEC, the admin user can easily customize an appropriate recommendation message and automatically send it to all VEC members.

V. Conclusions And Future R&I Insights

The proposed Research Algorithms' and Business Intelligence Tool (RABIT) offers advanced services to progressive utilities to cope with the continuously increasing competition in retail electricity markets. Utilities can thus lower their OPEX, increase their business profits and offer better QoS to the end users. They can also make their portfolio more energy efficient towards the clean energy transition era.

As future work, apart from data analytics, optimization algorithms will be integrated in RABIT to achieve even better results. During the next months, as SOCIALENERGY real-life trials will take place in Greece, more behavioral datasets (BDA) will be available and will be integrated in the existing VEC creation/dynamic adaptation algorithms incurring better performance evaluation results, too. This, in combination with more available OSNA, will offer more degrees of freedom for RABIT's administrator to define new business objectives and provide more interesting digital services to end users. Finally, the use of proposed P-RTP and C-RTP mechanisms to trade aggregated flexibility assets in emerging EU flexibility markets (e.g. by providing flexibility services to DSOs/TSOs/BRPs) will be further investigated.

Acknowledgment

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