Demand Side Management via Prosumer Interactions in a Smart City Energy Marketplace

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***Abstract*—Future smart cities are expected to be very large and complex ecosystems, where interactions among the various involved entities may lead to emergent behaviours (system of systems characteristic). Managing better the energy footprint is one of those challenging goals, and the smartgrid may provide a key tool in achieving that. We expect that smart city neighbourhoods will be more autonomous and able to manage more efficiently and dynamically their energy by taking into consideration local resources, prosumption and needs of their stakeholders. Additionally they will be able to interact with each-other and enable the smart city to dynamically take advantage of its optimal resource usage. We explore here directions that we follow in order to realize this view with the help of the smartgrid infrastructure, prosumer interactions, enterprise energy services and neighbourhood energy marketplaces.**

I. Motivation

THE emerging smartgrid concepts, go beyond simple smart metering and promise apart from more visibility of the electricity consumption at user side, better energy management by better interaction among all smartgrid stakeholders. The core of smartgrid depends on the usage of modern information and communication technologies [1] that will enable real-time bidirectional communication with all (old and new) participating entities. This will lead to the enhancement of existing processes but more importantly will enable a new generation of (collaborative) services and application that are not possible today.

The fine-grained monitoring of energy expected to be possible, will be coupled with advanced control capabilities. Every device and system in the smartgrid era is expected to be able to provide information (either directly or indirectly) with respect to its energy prosumption (i.e. consumption and/or production) [2] as well as additional flexibility in scheduling its load. This fine grained information, means that for instance our prediction and behavioural models for domestic and industrial energy planning and management will need to be extended to accommodate (i) real-time information monitoring, (ii) flexible customizable load behaviour and (iii) real-time management (control). Additionally we will see the emergence of the communityware smartgrid [3] i.e. the focus will shift from stand-alone domestic users to dynamically-built groups of large numbers of users (industrial or domestic) that will have the critical mass to impact the grid operation.

Due to complexity of the multiple smartgrid stakeholder interactions at several layers, it is mandatory to look at the smartgrid from the network viewpoint [4], as an ecosystem where collaboration [5] and information-driven interactions characterize it. The bidirectional information exchange will put the basis for cooperation among the different entities, as they will be able to access and correlate information that up to now either was only available in a limited fashion (and thus unusable in large scale) or extremely costly to integrate. The emerging Internet of Things bears the hope that networked embedded devices that lie in heart of the smartgrid will not only be connected but will be able to exchange info over the Internet in an open way. Today we already have several examples of tiny devices depicting their basic functionality (e.g. status reporting, control functions etc.) in a service oriented way, which brings us one step closer to realize the vision of an Internet of Energy.

Market-driven interactions have been proposed as a promising potential interaction method due to the monetary incentives involved for the participants. In the Internet era an online marketplace is an thriving concept as it overcomes potential accessibility issues. Marketplaces where smartgrid stakeholders may interact are envisioned in smartgrid roadmaps [6], [7], however it is not clear how they should be structured, operated, what their limits, conditions and benefits might be. Several projects make investigations towards this direction; as an example, the NOBEL project (www.ict-nobel.eu) envisions that neighbourhood/district-wide energy marketplaces could be considered within a smart city where prosumers may interact portions of their prosumed energy [8].

II. Emergent Energy Management

Today energy management is done mostly at standalone mode among the stakeholders within a smart city. This means that for instance a smart building is trying to optimize its behaviour internally towards better use of its energy footprint, a smart house is trying to optimize the use of its devices, and a distribution system operator (DSO) is trying to predict and manage the energy on the smart city neighbourhood. However overwhelmingly all of these efforts today are disconnected from each-other, and do not cooperate while in the best case some Demand Response (DR) mechanisms are in place [9].

Demand Side Management (DSM) attempts the modification of consumer demand via methods such as financial incentives and education. If consumer behaviour could be coupled to the true price of the electricity e.g. by charging less on peak hours, then consumer behaviour might (considering also other user constraints e.g. comfortableness, availability etc.) change by shifting activities to times where electricity is less expensive. The smartgrid heavily invests in this direction, with the majority of trials relying on dedicated on-premise installations (energy management systems) or on timely communication with the smart meter.

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While DSM works in practice well for predictable shortages, it is often that unforeseen failures e.g. damages at equipment may create problems in very short time-frames, hence DSM must be able to react in real-time to avoid power blackouts. Thus, to harness the true DSM benefits we must rely on the real-time interaction among the stakeholders, be able to monitor in real-time the energy price and apply the necessary control e.g. by dynamically rescheduling of processes or parts of them, and be able to change the energy prosumption modes of devices e.g. turning them on/off/standby etc. depending on their cycles and overall process they participate in.

In the future smart city context DSM will get more challenging as the energy prosumers are expected to exist and hold distributed energy production (e.g. PV panels) or prosumption (e.g. electric cars) facilities, which once "aggregated" and operated intelligently may be treated as virtual power plants (VPP) whose resources are distributed within the city. The key lies on the emergence of such groups and the effective interaction with them [3]. The optimal usage of local resources and the benefits they offer e.g. negligible transmission costs due to physical proximity may provide a promising element for the success of local stakeholfer interactions e.g. via a local energy marketplace.

Additionally integrating the prosumer's flexibility to express and reschedule his processes for a financial e.g. by trading it to an energy market, may also be another promising element that relies on future knowledge (expected behaviour) which in turn may empower prediction and optimization algorithms. Following the system of systems approach, it is expected that within a smart city, neighbourhoods/districts will be operating according to their citizens' benefit and try to achieve energy efficiency as well as an equilibrium between energy offer and demand by significantly integrating local energy resources and tapping in to their member's behaviour and interactions. These neighbourhoods may operate marketplaces in order to ease interactions among their users. Trading on these marketplaces not only energy, but also flexibility to change the energy signature, will give rise to the Prosumer Virtual Power Plants (PVPP) [2], [3] which can alter their behaviour dynamically depending on the flexibility of the prosumers that constitute them.

Community member interactions in a neighbourhood/district within a smart city may lead to the emergence of more intelligent global behaviour, unknown to the individual members. Typical example from the math and computer science domain is the swarm intelligence; the collective behaviour of decentralized, self-organized natural or artificial systems. Since the smartgrid is seen as a very complex system of systems, emergence i.e. the way complex systems and patterns arise out of a multiplicity of relatively simple interactions, is of extreme importance. Potential goals such as prediction of prosumer groups energy behaviour may assist in better planning and achieving targets e.g. energy efficiency, CO_2 reduction etc. Additionally from the economic domain we have a perspective on how behavioural attitudes depend on incentives and expectations, while from the social science we get insights on interactions among communities and populations. Since the smartgrid domain is not only a multi-disciplinary one, but will also be driven by multi-dimensional networks operating over a sophisticated cyber-infrastructure [10], integrating lessons and ongoing research targeting highly interconnected communities may be of help in understanding the complex emerging phenomena.

III. Market roles, interests and interactions

An energy market is one possible direction towards easing the interactions among all smartgrid stakeholders within the scope of a smart city. It is not clear how these markets will operate and what the minimum requirements are in order to have them functional and beneficial for their participants. Market driven approaches are under investigation in several ongoing research projects such as SmartHouse/SmartGrid (www.smarthouse-smartgrid.eu), NOBEL (www.ict-nobel.eu), e-Price (www.e-price-project.eu), MIRABEL (www.mirabel-project.eu). The experiments vary from a fully functional market down to leaner versions of it where e.g. prosumers will not trade there their whole electricity prosumption, but rather part above their base load and possibly flexibility; hence act as an additional functionality to existing contracts with the energy retailers.

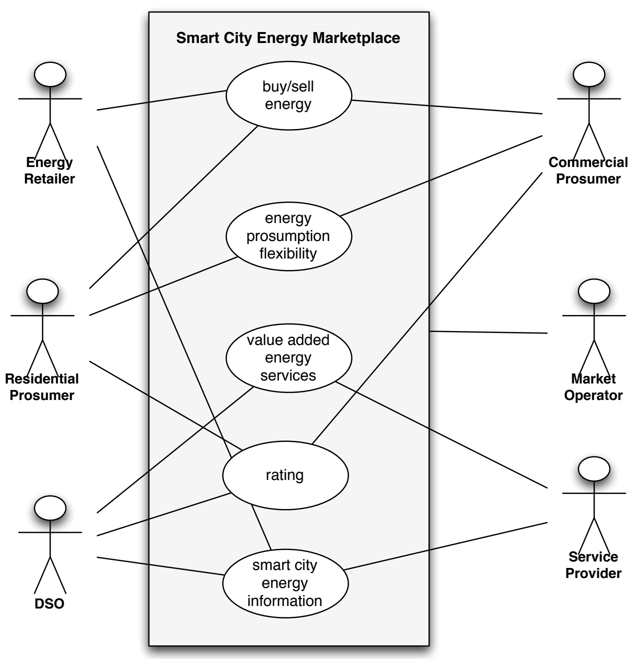

Fig. 1. Indicative interactions among market stakeholders

Some key stakeholders active in a local marketplace are depicted in Fig. 1. At first stage only partial coverage of energy in a neighbourhood is expected to be transacted; hence in the mid term neighbourhood energy marketplaces are expected to operate as complementary efforts to the existing market schemes and business relations. In the longer term, the whole electricity of a neighbourhood could be transacted over it – hence a microgrid market-driven approach could become a reality. If we have a view at potential stakeholders we can distinguish the energy retailer, the DSO, commercial and residential prosumers, service providers e.g. Energy Servicing Companies (ESCo), a market operator etc.

A. Energy retailer

The energy retailer provides a longer term contract to the customers, while in parallel is managing the risk involved in purchasing electricity at spot markets and electricity pools. It is expected that they still sell some energy via neighbourhood marketplaces and also cover the extra load that the user might require (but didn't transact over the marketplace). The last is seen as a fall-back mechanism and generally the expectation is that the price paid for electricity will be higher than the one acquired in the live market. For the energy retailer the market offers an opportunity to get a glimpse of the future smart city energy information as this is depicted via the transactions on the market. This may assist towards better planning his strategy when interacting with the national level markets and with the overall prediction for his customers.

Key benefit for the energy retailer is among other things the better understanding of the smart city prosumers. This might assist towards better shaping his strategy and prices, as well as get an insight on the future behaviour of the city. This could lead to the adoption of new business models e.g. offer new services to his customers or expand to new market segments e.g. offer PV not only energy per contract, but energy related services. A typical example might be a new tariff specially designed for electric car owners that includes roaming between various providers at an attractive price, or negotiation via the market for smoothing energy peaks etc.

B. Distribution System Operator

In the future smart city, several of its neighbourhoods will be supplied possibly by different local Distribution System Operators (DSO) who coordinate with a few Transmission System Operators (TSO). The local DSOs are in charge of providing the last mile infrastructure, distributing the electricity to the end users. Via the marketplace they can also acquire information about the future energy consumption in parts of the city which can be compared against the available capacities. Additionally in the longer term, the DSO may offer value added energy services e.g. real time metering, predictive maintenance, or even market the infrastructure available capacity so that it can be integrated dynamically in the electricity prices transacted over the energy marketplace.

Key benefit for the DSO would be the better understanding of the network utilization as well as the insight towards future behaviour based on market transactions. The last could lead to better planning, better utilization and potentially assist towards strategic investments on the infrastructure itself within a smart city. By using local energy production, the existing transmission lines might be better used while investments can be targeted (e.g. depending on the energy needs of as specific neighbourhood) where they are needed. Adjusting the transmission costs of the lines may have an effect on the marketplace energy prices (if coupled), hence it will be possible to indirectly control the utilization of the line and avoid peaks or increase consumption when needed.

C. Residential Prosumer

The residential prosumer is one of the key stakeholders to be involved in the smartgrid era. His increased energy awareness coupled with the willingness to adjust his energy behaviour depending on dynamic indicators such as a price signal drive DSM. There are several ways of participating in a marketplace (some of which are depicted in Fig. 2) and his motivation is incentive related; mostly monetary or personal interest (e.g. assist in using green energy). Existing concepts for DSM depend on harnessing prosumer's flexibility in tuning their energy signature. The marketplace could play a significant role in enabling the prosumers to take advantage of their energy flexibility in exchange e.g. for lower prices or other value added services. It is expected that this market participation will be fully automated either in a standalone manner via user-configurable agents [11] or as part of larger groups of prosumers [3].

Key benefit for the residential prosumer would be the possibility of optimizing his energy usage by adjusting his behaviour to dynamic market prices as well as have some financial benefits for the electricity he produces (and doesn't use). Potential emerging marketplace services such as analytics on his behaviour etc. might further assist him in optimizing his strategy at the marketplace trading as well as the production and consumption of energy. Additionally this could be a step towards a negawatt market, where for instance he could resell part of the fixed energy he has contracted with a local energy retailer and he will not use.

D. Commercial Prosumer

The commercial prosumers are mostly heavyweights when it comes to energy production or consumption. Typical examples include an industrial facility, public infrastructure (e.g. public lighting system), shopping malls, wind turbine farms, electric car fleets etc. It is expected that by being able to control/reschedule energy hungry processes, the commercial prosumers may benefit from lower electricity prices, but more importantly they could sell this flexibility to the market which could result as a new source of revenue. A performance indicator risk/cost analysis of (controllable / highly predictable) internal processes and dynamic external conditions (e.g. need for electricity at peak time) can be evaluated and transacted over the marketplace. This could be potentially very interesting for market-negotiated DSM as it will enhance the collaboration among production and consumption within a city neighbourhood, leading to more efficient usage of the available resources.

E. Market Operator

The market operator facilitates the market and the associated services including for instance billing, clearing, transaction security, identity management etc. Typical models similar to the ones existing in the Internet world such as eBay, could be considered to facilitate prosumer interactions with the rest of the smartgrid stakeholders. It is not clear if any of the existing stakeholders (e.g. the DSO, utility) could slip into the role of the market operator or if this will be a new independent authority trusted by all stakeholders. In extreme scenarios where the whole energy in the neighbourhood is transacted over the marketplace, this could lead to significant market loss for energy retailers – hence they might be interested in taking up this energy service business dimension (marketplace management) as a new revenue source.

F. Service Provider

Having in place the smartgrid envisioned infrastructure, over which advanced services can be realised such as real-time smart metering, management, information exchange etc. it is expected that will also lead to new innovative applications and services. Third party service providers will be able to identify market white spots and offer new functionality (i) that can be traded on the marketplace and (ii) that can be integrated as part of advanced services in the core marketplace functions. A typical example might be analytics e.g. energy prediction which would be useful for residential prosumers that would like to consider their strategies for buying/selling energy in the marketplace. Another example would be aggregation of end-user energy production and selling of it on the market, hence acting as a mediator between the end-user and the other market stakeholders. Alternatively offering other services e.g. management of user's device according to the transacted energy, notifying him of market opportunities, configuring intelligent trading agents [11] on behalf of the user etc. are some of the manifold functionalities that could be considered to be provided in a neighbourhood marketplace.

IV. Market integration with prosumer devices

For the trading of energy to neighbourhood marketplaces to take off, basic requirements need to be tackled and this includes (i) monitoring and (ii) management (control). More specifically it should be possible to monitor (preferably in real-time) the energy production or consumption in order to feed it to the appropriate services; hence we see heavy investments in smart metering. However this is not enough. Management (soft control) of on the prosumer side is also needed so that energy strategies can tune the infrastructure to the business transactions done in the marketplace. Hence not only users [2] but also their prosumer devices need to be loosely coupled with the market.

Integration of prosumer devices with the market implies:

- Capability of reporting energy production or consumption. This should be done preferably over non-proprietary open technologies. For instance web services / REST over Internet have proven themselves as good candidates.
- Capability of adjusting the energy prosumption depending on external interactions such as price information. The latest implies not simply turning a device on or off, but offering intermediate states as well as being able to split the different process cycles it can operate to states that can be resumed later (for the task to finish).

Popular examples used nowadays to demonstrate potential impact of smartgrid refer to washing machines or fridges that monitor electricity price and adjust their behaviour i.e. operate in order to minimize costs for their owners. As depicted in case (ii) in Fig. 2, a prosumption device may do so, if it possesses the communication capabilities to contact external sources of information as well as the intelligence to process market responses and tune itself to the user's objectives. Although technology trends on the device world [10] may make this a feasible goal, there are many open issues associated with the security, privacy and risk of doing so. From the network viewpoint also, it is questionable to what extend this makes sense, as one will have autonomous devices selfishly trying to achieve their goals (while potentially considering market input) without however cooperating nor considering the bigger picture (rather focus on their goals and understanding).

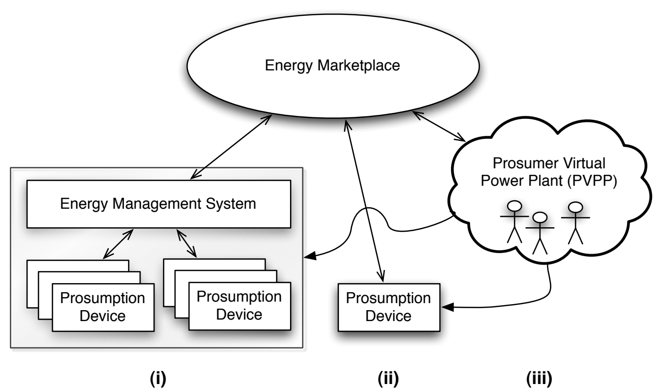

Fig. 2. Potential prosumer device interactions with the market

An approach that is more probable to be followed in the mid-term is depicted in case (i) in Fig. 2, where devices integrate or cooperate with an energy management system (EMS). The EMS hosts the intelligence to manage the different devices in its infrastructure according to the goals of the user, and optimize (e.g. via negotiation) the device behaviour to those goals. Note that this enables also the integration of legacy devices (by functionality wrapping); a step necessary as we migrate towards a more advanced infrastructure but still in a step-wise manner. This approach enables the user to interact with a single system which acts on behalf of him in the marketplace. Additionally smart home goals can be pushed down to the individual devices without the user having to explicitly interact with all of them. Nevertheless though, we still have the EMS acting on behalf of a standalone user (while potentially considering market input).

A more promising approach in our view is depicted in case (iii) in Fig. 2, where the users form communities/groups that when large enough can be considered a Prosumer Virtual Power Plant (PVPP). Contrary to the classical VPPs where the coordination of distributed generation is managed, here both distributed production and generation are managed towards the community-wide [3] goals that the prosumer has chosen to adhere to. It is expected that PVPPs will be able to both monitor and manage prosumer infrastructure, hence constitute a layer that can interact both with cases (i) and (ii) in Fig. 2. Here prosumer network-wide goals can be set and followed, while the critical mass guarantees a significant impact on the energy marketplace. Additionally the rise of such communities that realise PVPPs and the interactions among them will need to be studied from the network viewpoint [4] as smart city wide energy behaviour might emerge and be tuned potentially via the market.

V. The NOBEL project approach

The NOBEL project [8] is targeting the better energy management at neighbourhood/district level. This is envisioned to happen via enterprise services integration and interaction with the prosumers, while surplus energy can be traded in an energy marketplace. Hence it partially covers the issues we have analysed so far.

In a smart city each neighbourhood/district is expected to have an Electricity Monitoring and Control System (named NOEM in NOBEL project), assisting the DSO in having the overview by providing analytics as well as enabling the management of the energy. The information that such services will process and depend upon, come from the network (smart meters, local distribution equipment, concentrators, network analysers, etc.), the prosumers interacting with the network through applications such as a Brokerage Agent Front-end (BAF), or the relevant local DSO. NOEM and BAF are exmaple of mash-up applications composed by various enterprise services.

It is expected that users will interact mostly via mobile devices due to their high penetration. These will provide him with real-time data, and foster direct interaction with the user who can not only receive info e.g. energy consumption, but also can connect e.g. to the online marketplace to buy and sell electricity [2].

As an example of a commercial prosumer, the NOBEL project interacts with the public lighting system. This is possible via interaction of the market and the EMS responsible which in our case is the Neighbourhood Oriented Public Lighting Monitoring and Control System (NOPL). Commercial prosumers can better predict and manage their internal energy management processes, which impose some constraints but also provide new capabilities to improve the energy efficiency of the targeted neighbourhood/district. In the case of a public lighting system as the one used in the NOBEL project, the main constraint would be the need to respect at any time the contractual obligation of providing a public service: major disruptions on the service could affect not only the well-being of citizens but also its security and safety. In this way the monitoring but also mainly the control capabilities should be highly robust, which may limit the number of feasible energy-saving solutions.

NOBEL explores the importance of local energy markets to enable better energy management at neighborhood level; which implies the horizontal interactions among the prosumers (via an energy marketplace) and the ability to provide analytics at local DSO level. An overview of the envisioned interactions is depicted in Fig. 3. The different stakeholders such as prosumers and DSO (via NOEM) interact while exchange of information in order to have cooperation among such marketplaces at smart city wide level is also considered.

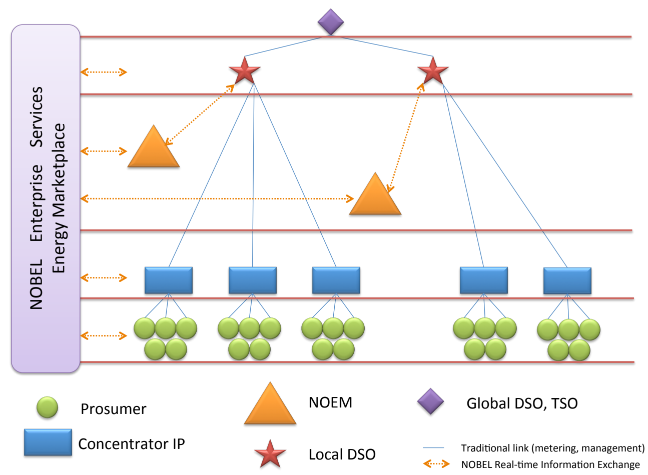

Fig. 3. The NOBEL approach for supporting neighbourhood energy trading and management

The concepts are expected to be trialed in 2012 in the city of Alginet in Spain. We plan a number of prosumers to be able to use the brokering capabilities provided by the enterprise services and buy and sell electricity in the local marketplace. The interaction is expected to be mainly done via mobile devices i.e. smartphones and tablets, hence special application front-ends are developed (e.g. the BAF). Besides the normal residential customers in the trial entities controlling the public infrastructure will also be possible. As such the public lighting system of the city will be used to act as a balancing partner twofold: (i) at the first stage by offering its flexibility to better balance the local energy needs, as a result of management from the NOEM, (ii) and later experiment by having it offering this functionality over the local energy market.

We have already mentioned that the smartgrid is a complex ecosystem of multiple smaller systems. Such a subsystem is also the neighbourhood, whose energy signature depends heavily on the utilization of local resources available which is of course bound to several complex conditions such as weather, behavioural patterns, business interactions etc. An emergent behaviour appears when a number of simple entities operate in an environment, forming more complex behaviours as a collective.

The NOBEL project does not offer "intelligent" energy management in the classical sense. There is no centralized component responsible for applying a global strategy for achieving energy efficiency. We follow a distributed approach where intelligence relies at several layers and is combined in order to empower different strategies (possibly also competing) for the users of the infrastructure. The real "intelligent" energy management followed is that of the market and the outcome of the interactions among the users. As such in NOBEL the intelligence is an emergent behaviour that may lead to better utilization of all local resources in a very dynamic system.

Our aim in NOBEL is to offer the basic tools and infrastructure so that the stakeholders involved can interact at a large scale and lead to an emergent intelligent energy management characteristic that depends on market dynamics. Several efforts exist today where agents take the role of either collecting data and deciding based on intelligent strategies or negotiations e.g. the PowerMatcher [12], SESAM [13], MAGIC [14], D'ACCORD [15], as well as BEMI [16]. We expect that in the future smart cities will be very complex ecosystems whose interactions will be difficult to be simulated due to the increasing complexity, hence it makes sense to take a system approach rather than focusing on the explicit behaviour of discrete players.

Diving into the various components within the NOBEL system one can identify several layers where intelligence may be hosted. The smart devices offer some of their functionality as an event-enabled service. This allows the next level e.g. a concentrator to selectively acquire and process information [1] coming from multiple devices. An enterprise system would be therefore in position to push intelligent queries within the network that are partially processed on the concentrator and partially at the device, while synthesizing back the results. This is of key importance for enterprise systems as they can realize distributed business processes by hosting the business logic where it is needed (usually near to the point of action) [10].

Apart from the nested intelligence in the different layers, we expect that by provisioning real-time information to all stakeholders, existing services will be enhanced and new ones will emerge. Today this is complicated as no standard toolset exists for building smartgrid services, however within NOBEL we provide several of them in a generic form e.g. at enterprise services level. Since these can now be integrated at any layer, this may lead to more sophisticated approaches. Imagine for instance preventive maintenance on the concentrators and substations with the help of enterprise services while in parallel the respective workflows can be immediately kickstarted. Alternatively imagine user-hosted agents which monitor the energy prices in the marketplace, the calendar of the user and its future behaviour as well as weather conditions in order to assess a strategy for bidding according to the user's needs. The provision of the services envisioned in NOBEL has the potential to make reality such complex interactions at large scale. Interacting in a marketplace where multiple (complex) strategies will be present, equilibrium might be reached between demand and response by market interactions. The result will be a possibly autonomous market-driven system that will be able to better utilize its resources while it is self-maintained.

VI. Future Directions and Conclusion

Having energy marketplaces at neighborhood/district level within smart cities may be a promising approach towards market-driven demand side management. However even if the technical feasibility of implementing such energy marketplaces is in place, significant effort needs to be invested towards understanding and realising business models, cooperation concepts and clarifying the operational issues of such markets. Most efforts today simulate aspects of these markets however there is lack of a general simulator that could be used for comparative analysis that also considers the real world constraints of smartgrids. For instance issues related to the modelling of neighbourhood transmission line capacities, coupling of those capacities to automated network management for large-scale distributed prosumers, as well as the self-driven vs. collaborative efficiency approaches will need to be investigated.

Managing the real-time trading of energy under consideration of the high dynamics of electricity prosumption is going to be challenging. Approaches that are interaction-driven and not technology focused, that use a well defined infrastructure with open services are needed. Today there is ongoing work towards the communication standardisation, however we miss the data models as well as generic (standardized) capability and service functionality that we can assume either at infrastructure or at prosumer device level to exist and build upon.

Many of the investigations rely on the input of the prosumers and assume honesty and accuracy from their side. However since this is an incentive driven system composed of mostly self-interest stakeholders, we need to investigate the misrepresentation of information provided by the prosumers either on-purpose (maliciously in order to increase their profit) or because of inability to do otherwise (e.g. not good enough prediction tools to estimate their prosumption or good enough management tools to adhere to the in-marketplace transacted behaviour). Traditional approaches of regulation and audits existing e.g. in national markets, will heavily need to be readjusted for large-scale distributed prosumers while existing Internet approaches such as rating and recommender systems may offer assistance while transacting in energy marketplaces.

The coexistence of multiple such energy marketplaces within smart cities and regions as a second level markets and their coexistence with national markets will need to be investigated. This will have to include internal conditions arising from the market player interactions as well as external ones e.g. from physical or external phenomena that could impact or constraint their operation. The national electricity markets are complex enough and how the neighbourhood markets could integrate the lessons learned and adapt experiences to their needs is a challenging task.

Finally it is clear that the user participation in such markets needs to be fully automated by integrating goals and preferences of the user into intelligent agents that act on his behalf. Such systems will need to resolve several security, risk and privacy issues on the smartgrid stakeholder as well as the market itself. Automated trading agent strategies based on those preferences will need to be developed, and both non-cooperative and cooperative angles will need to be investigated for efficiency, scalability and stability within a smart city neighbourhood. The existence of generic simulators for the prosumption and market itself as well as the possibility of mashing them up in order to create more complex systems and compare their results is urgently needed.

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