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Blockchain and smart metering towards sustainable prosumers

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ABSTRACT
The trend in the energy market has led in the last few years the increase in demand (eg the spread of electric vehicles) and an increase in volatile renewable energy sources (PV, Wind, etc.), a reduction in the use of fossil fuels, that destabilize the grid leading to black outs.
The electricity grid is developing in a distributed network, so the connected energy markets are moving towards a new decentralized structure, where renewable sources and storage facilities (EVs), will have a significant penetration and adoption by energy customers, with the intent to provide sustainable solutions.[1]
Balancing the demand and supply of electricity, in a system dominated by random elements, such as solar and wind production that depend on weather conditions, combined with the highly variable demand from domestic users, must lead to a new model of consumers and producers at the same time that is the so-called Prosumer and will be a challenge of great importance.
With this paper we want to verify how the smart communities, made up of Prosumers, within smart cities, are the key to the new electricity distribution, based on ICT, IoT and smart metering. A significant contribution will be provided by the Blockchain to make the energy networks and related economic transactions secure and reliable.

Keywords: Smart Grid, prosumer, smart metering, RES, EVs; smart devices, IoT, smart home, Blockchain, REScoin.

I. INTRODUCTION

Key aspects of future electricity power systems are smart grid, electricity market, control management, infrastructure construction, decentralized energy soruces and charging of EVs. The profiles of energy demand have changed, becoming increasingly unpredictable, due to the effect of the introduction of renewable sources, which are used for self-consumption, limiting the requests to the network; the development of intelligent devices, which can be controlled with control strategies, through departures, programmed, modulated, anticipated, delayed, determining an extremely flexible demand, and finally by the penetration of the strong growth of EVs.
The evolution of the electrical system brought to the definition of a new figure: the prosumer. In fact, the energy user can consume energy, but at the same time produce it (for example with a photovoltaic roof panels, EVs storage, mini-wind, etc.) deciding whether to consume part of this energy locally or selling the surplus to the smart grid.
This brought a substantial change in the energy market, which in the short term will have to balance the fluctuations of the generation, deriving also from the introduction of the prosumer into the network, with the request for energy from loads, which can be managed and controlled by remote, with the objective function to minimize procurement cost for energy through trading decisions based on the price differences across time.
The analysis of control of energy flows, have greater applications for domestic users, whose behaviors can be more easily simulated and predictable, while in a building used for work activities, the variables are multiple and complex in relation to the type of activity work, personal, schedules, etc.
In addition, it is easier to encourage those who pay for energy consumption (such as domestic users) to behave responsibly, rather than to an employee, who does not care how much he will pay for his consumption.
The smart meters become the backbone of smart grids enabling wider integration of energy and Information and Communication Technologies (ICT). Smart meters and associated technologies enable realtime, two-way communication between suppliers and consumers – thus creating more dynamic control and interaction of energy flows.
For this reason, with this paper we analyzed the behavior of domestic users, Prosumer, to arrive at the definition of a new model of energy market with the integration of Blockchain.

II. SUSTAINABLE PROSUMERS AND DEMAND SIDE MANAGEMENT

A key element for the development of smart grids is that the electricity supplied and required by consumers is more flexible, this can be achieved thanks to ICT, Information and Communication Technology, the IoT, and smart meters, integrated with Smart Grids .
The smart district users will not be simple users but prosumers, ie they will have a proactive role, following the generation or the utoproduction: PhotovoItaic Panels (PV) and micro combined heat and power systems (flCHP) that generate electricity and heat for individual households or to community [2]. Figure 1 shows the network for the Smart Home. This system consists of the AC and DC link, unidirectional

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converters for RES, the bidirectional converter for EVs, the control circuit, and other relevant power electronics.

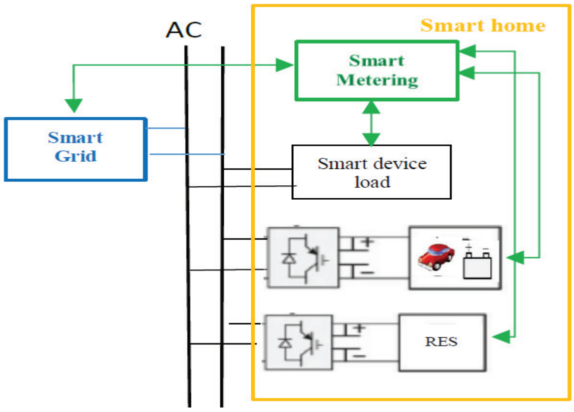

Fig.1 Network for the Smart Home

This will allow to manage peak flow and Smart Grid in a more flexible and efficient way [3].
The demand side of the most flexible electricity system in its consumption is addressed in the Demand Side Response (DSR) concept. The concept then turned into Demand Side Management (DSM) which includes all implementations on the demand side of the energy system [4]. Demand Side Respone is considered to be a key factor in the future electricity market [5].
Demand Side Management and Proactive demand are expected to facilitate the ability to take on a significant dynamic role in balancing electricity in future decentralized power systems.
Smart meters constitute a potential important link between buildings and the electric grid. Today electricity consumers have the opportunity to know how much they are paying for their electricity consumption in real time [6].
This awareness implies that consumers have the opportunity to decide at what price to pay for energy, simply by modifying their behavior.
At present, however, price differences for different consumers are too small to provide sufficient incentives for consumers to change consumption patterns. In fact, small price changes and low electricity prices are not sufficient to motivate investments in DSR. Increased price volatility could increase the ability to implement Demand Side Response.
To realize a DSM, it is necessary to introduce elements that make the Smart Grid and the energy market flexible to optimize the energy trading and grid balancing capacity on the wholesale market [7].
Intelligent software agents exchanging energy with the wholesale market will have to follow the optimization strategy imposed for the best interest of prosumers, e.g. the one which maximizes profits, prescribes the commercial behavior of the intelligent agent and specifies the general rules when the sale of energy to the network is more advantageous. The agent must take the following into account when maximizing the profit. The goal of maximizing profit can be defined as follows:

$$\arg\max_{S,B} \sum_{t=0}^{24} (S_t \times P_t) - [B_t \times (P_t - D_t)] \quad (1)$$

where:
S is the amount of energy Sold to the SG
t is the specific time in the 24-hour interval
P is the price for energy,
B is the amount of energy Bought by the SG
D is the cost of depreciation of self-handling systems, on individual life cycles and reported at time t

this net of specific returns e.g. of the conversion from CC to AC. So the Trading Agent maximizes profits by optimizing the revenues it obtains from the sale of energy in every hour and the costs deriving from the charge of its self-consumption, in a certain time interval at any hour plus the amortization cost of the PV, Wind, Micro systems CHP.
As a result, network balancing is a key element and smart grids play a central role in the management of the energy market, where different brokers compete, representing energy suppliers, energy retailers, energy consumers and prosumers, in this way, interests of all participants in the energy market are considered. The price of energy will be determined dynamically, based on supply and demand. [8]

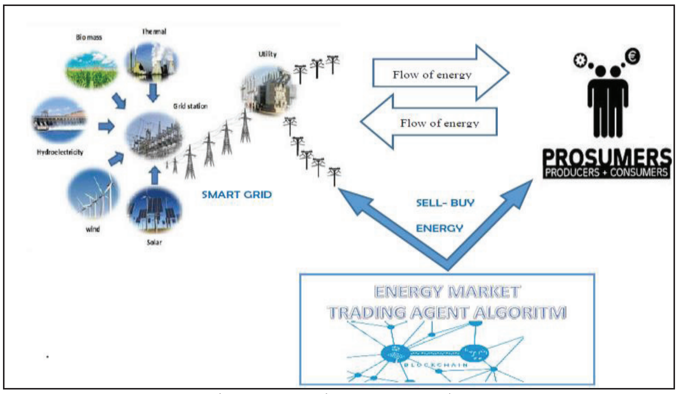

Fig.2: Dynamic Energy Market

Figure 2 shows the dynamic energy market, where brokers are no longer present, which are intermediaries of the electricity service companies, both on the retail and wholesale markets; model the behavior of individual customers, their assessments for energy tariffs and risk preferences.
In fact, the prosumer through smart meters, define different consumption patterns (for example they are dependent on the climate) and preferences, which imply different fixed or variable prices schemes,
Furthermore, in addition to stability, the market must contribute to the implementation of RES energy, with affordable energy prices. This also applies to Prosumers, for whom the Smart Trading Agent obtains profits for Prosumer (for example by RES or from electric vehicles that charge in economic hours and supply energy to the network).
The complexity of the problem lies in the price mechanism: by selling and purchasing a certain amount of energy, the agents affect the price of energy compensation, which in turn influences the optimal sale and purchase amount, and the

market is not able to to arbitrate the difference without adequate storage (eg without EVs). [9]

III. SMART METERING FOR DYNAMIC DOMESTIC LOAD

With this paper we want to highlight how it is necessary, in the transition to dynamic decentralized systems, to integrate smart metering, which recording, in a chosen time interval, domestic consumption, provide indications to delay or reduce the load.

The balancing of generation and demand within a smart energy community is realistic and efficient when it is a sufficiently large and diverse combination of consumers.

Smart districts are formed, intelligent communities of appropriate size, in which active demand management at the distribution level will be necessary to balance intermittent generation and demand of energy [10].

This will result economic benefits for the different actors at stake (ie consumers, public services and governments), for example would be to avoid the high operation cost of spinning reserves.

The Smart District will be composed of hundreds of families with different types of electric loads, they are a set of homes and buildings with various forms of renewable energy production, and related energy consumption for domestic loads, lighting, building automation systems, fleets of EV.

Therefore, through the Trading Smart Agent Software, the control system and management between demand and supply of electricity, self-production and on-site consumption, extremely volatile, will be modeled also in consideration of the integration of smart devices with dynamic control in real time, user behavior, for obtaining the energy balance in the SG and with secure, stable electrical power that is derived as far as possible from renewable energy sources (RES) and managed to minimize for example electricity costs.

The modeling of the domestic electricity load is known: it must start from a certain number of dwellings, considering the number and type of loads typically present in each single dwelling [11], [12], [13]. The model must consider the period of the year, in relation to the different uses of electric loads, related to air conditioning and lighting.

The control algorithm, in compliance with the set objective function, see (1), must take into account the following objectives,

- Shifting charge: the consumption of some devices can be deferred over time, causing the smallest disturbances to the comfort of the customer;
- Load reduction: performed only in special or emergency cases, as they are situations in which its execution has undesirable effects for consumers.

Domestic loads that have a form of thermal storage are ideal for shifting the load over time, such as refrigerators, which have a discontinuous operation, typically with a 20-minute turn-on and a 40-turn-off.

In particular conditions it is possible to modify the operating time, as it does not have any urgency in the re-activation. Furthermore, conscious behaviors can be induced, advising not to open it continuously during that time interval.

Of course, other loads such as dishwashers, washing machines and tumble driers are also suitable for starting changes, so it is possible, knowing the type of load, the typical operating time and the preferences of the Prosumers, how to set the start / stop loads, in order to optimize the energy demand.

Through smart metering it is possible to know when the loads are working and through a platform, with smart agent control algorithms, it will be possible to manage and distribute the domestic loads over time, also in relation to the priorities set by the individual prosumers. see Tab.I and we observe that domestic loads such as lighting and entertainment are considered essential, therefore their operation continues even during the emergency event.

Load in SH	Time (cycle)	Priority for SG	Priority for Prosumers
Smart Refrigerator/freezer	20 minutes	0	3
Smarter coffee	2 minutes	1	10
Smart washer machine	20-120 minutes	1	9
Conncected robot vacuum	30 minutes	2	14
Oven	20-60 minutes	2	11
Security lightning	10 minutes	0	4
Lightning in the day	in relation to the weather	1	5
Lightning in the night	8 hours	0	1
Smart dryers	5-15 minutes	2	16
Controlled shades	Few minutes	1	6
Air conditioner	in relation to the weather	1	8
Smart bathroom appliance	5-10 minutes	2	12
Smart entertainment	1-4 h	1	2
Home security	4-8 hours	0	13
Steam microwave oven	1-30 minutes	1	7
Small kitchen appliances	Few minutes	1	15

Tab.I time and priority of typical domestic load

The use of a smart device in a home is related to the number of people who are at home and active, and reflects the natural behavior of people who live by following their own lifestyle habits. Through smart meter it is possible to monitor the consumption and utilization trends of the various smart appliances, for example, the trends measured by a search are reported [14], by which the data can be extrapolated to determine a priori the management algorithm of domestic appliances, in relation to their typical use, with appropriate aggregated daily profiles (low use during the night, increasing during the early morning, etc.), see the following figures 3-8.

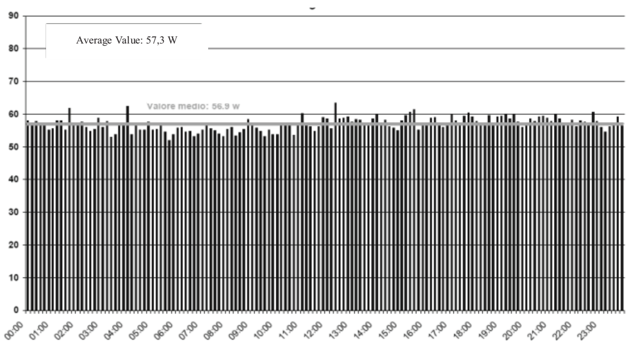

Fig.3. Daily loading curve for the refrigerator, July-August period

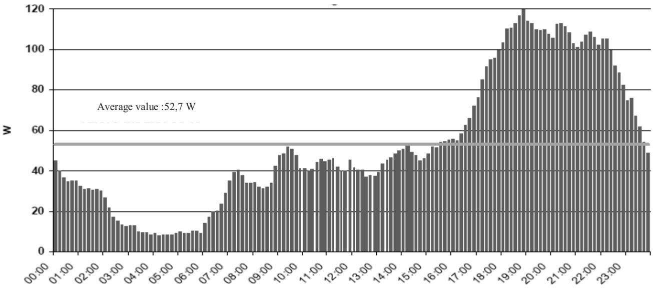

Fig.4 daily load curve illumination period

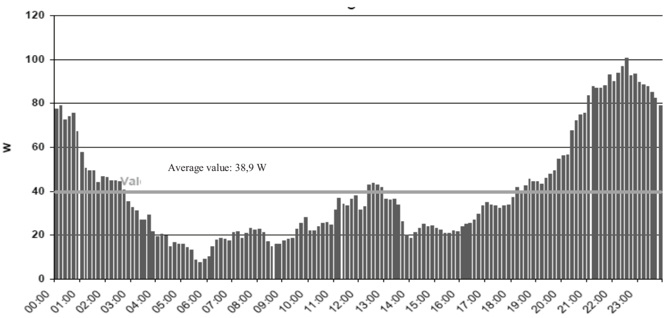

Fig.5 daily load curve lighting summer period

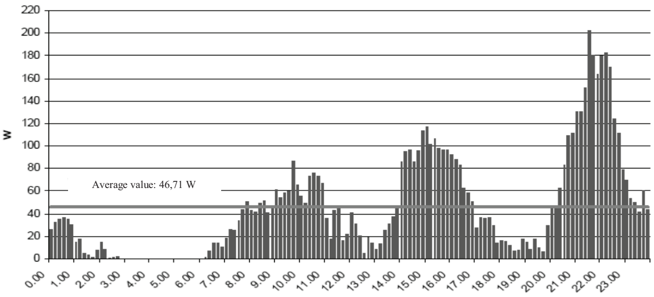

Fig.6 daily load curve for dishwashers

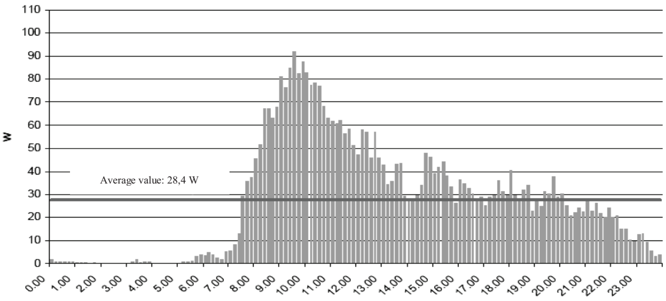

Fig.7: daily load curve smart washer machine

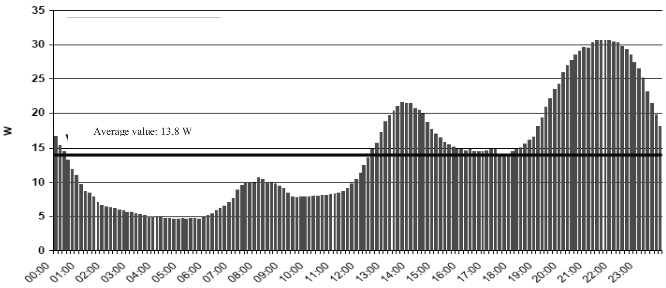

Fig.8: daily load curve smart entertaintment

The statistics are based on the measurement of a substantial collection of data, coming from the dwellings, through the Smart Meter this happens in a timely manner in each house.

These daily trends contribute to classify devices according to their use, with behavior that according to the literature [13]-[14] are of the type even smooth, stochastic or fixed behaviour as show in fig.9:

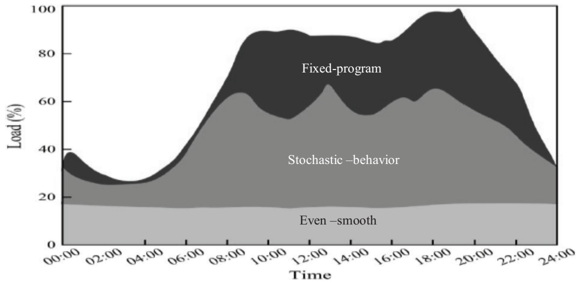

Fig.9: trend of the type of behavior of the devices

By assigning an activity profile to each appliance in the model, the variable probability of using the device throughout the day can be taken into account in a stochastic simulation. [15], [16].

To model the demand profile, the smart agent of every "n" house, a series of appliances is assigned which is associated with one of the daily activity profiles, which quantifies the probability of the specified activity, which can be taken as a function of the chosen time step (eg 1 minute) of the day.

Profiles must take into account:

- number of active occupants,
- the probability of using a specific appliance (whose type of use depends on time and season, increases in relation to the number of occupants) and those that do not depend strictly on the occupants, such as. Refrigerator, whose engine has a cyclic ignition;
- weekday or weekend;
- day or night;
- state of the appliance: ON, OFF, STANBY; for the latter two the behavior of the devices is predictable, while for the ON state, it depends on several factors (season, hour, day, etc.) and the trend as seen in fig. 9.

Another key element is the contemporaneity and the use of different devices. The power absorbed by the single "n" Smart Home, must take into account the totality of the loads in terms of the power absorbed by the individual loads, not working 24 hours a day, and the simultaneous operation of the loads themselves. The Power will therefore be:

$$P = K_{C1} \times P_{n1} + K_{C2} \times P_{n2} + \ldots = \Sigma_i K_{Ci} \times P_{ni} \quad (2)$$

where:

P_{ni} Nominal power of the i-th appliance

K_{Ci} coeffieciente that considers the contemporaneity of the loads used and the use of the i-th load.

These elements contribute to determining a previsional model of consumption of the i-th appliance, elements constituting the control algorithm that the smart agent system, for the "n" Smart Home, that will perform. These combined factors must determine the optimal choice, in respect of the condition (1), between the shifting or reduction load, as shown in Figure 10. Obviously, especially in the case of load reduction, prosumers would have a non-ideal situation, creating an inconvenience, but at the same time would have an advantage for the stability of the network, which must be quantified and / or monetized, through secure and integrated contracts with energy flows.

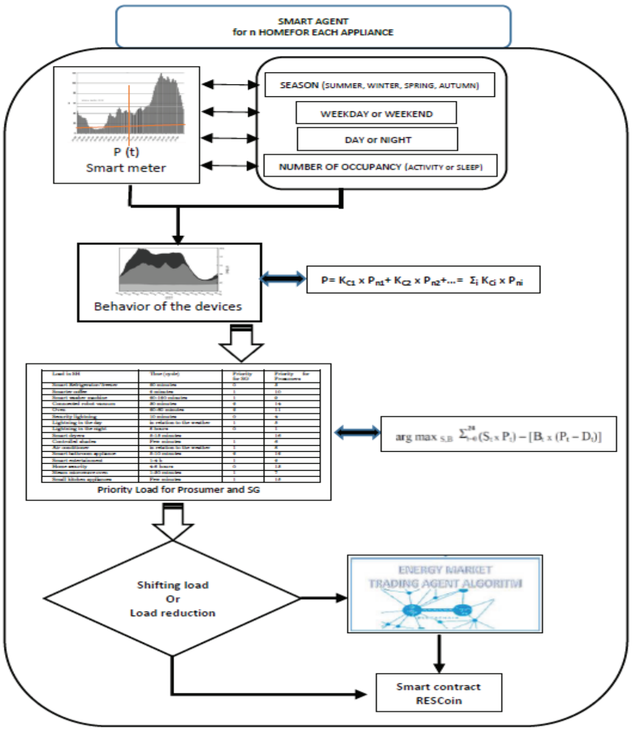

Fig.10: Flow chart of Smart Agent for n Home

IV. BLOCKCHAIN FOR SUSTAINABLE PROSUMERS

The energy sector is assuming considerable complexity, having to manage a multitude of data and in real time, this involves the need to create a new electrical network, flexible and safe, quickly and economically, which offers opportunities for new services, and greater economic value. Using emerging software and technologies associated with the Internet of Things (IoT), we can instill intelligence in existing infrastructures, as well as in a Smart Grid, with intelligent devices able to communicate with each other even if over long distances, but all this will have to be carried out with maximum security.

In fact, the security of systems related to smart metering, IoT, smart devices, SG and the energy market, will be the priority and one of the most important changes not only for Prosumers, but also for suppliers and policy makers.

Attackers can alter the transmission and can also access information. This issue must be discussed not only for deliberate attacks, but also for human errors or equipment failures [17]. The privacy of customers' energy data should be respected, because customers do not want to share their information to unauthorized persons or marketing companies [18]. Wireless communication protocols are more vulnerable because of air, being used for data transmission.

Blockchain software has become famous for its involvement with cryptocurrencies, but actually makes IoT truly possible. Although it is still being tested, this type of blockchain technology shows the real possibility that a block-link network can function within the power grid [19].

A big limitation of the current SG, is that local utilities, redistribute excess energy, often with significant losses, for example the consumer who can be on the other side of the road compared to a local energy source, must still go through the network and pay the complete retail sale for the energy generated by its neighbor.

Blockchain has the ability to change the electricity market, through the management of energy flows, of every economic transaction, of renewable energy certificates. The goal is to reach a decentralized system, where each user can become Prosumers, without having any more intermediaries.

Blockchain is a digital contract, multiple transactions constitute a block, which must be verified through an algorithm, which must generate/verify a hash, ie a code consisting of unique numbers and letters.

Hash algorithms (such as PoS-Proof of Stoke or PoW Proof of Work), are used to convert arbitrary length data to a fixed length, thus creating a hash. No 2 encrypted messages can be based on the same hash value, nor the hash value will provide information as to the content of the message [20].

Once the verified and correct version of a block is obtained from most other blocks, along with the other network participants, the BC can extends. As intelligent devices can communicate via IoT, through the BC you can send and store information and transactions, peer to peer [21].

The energy sector differs from the financial sector because the physical product itself (for example electricity) must also be included, see fig.10.

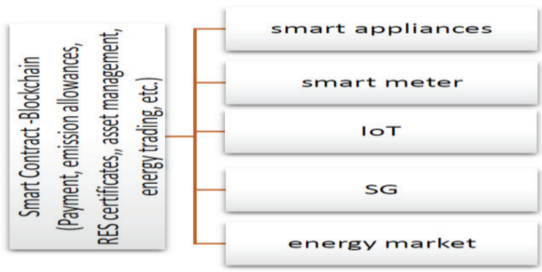

Fig. 10: Blockchain Energy sector

Transactions here are not just about values and information, but also about the energy trade that is delivered through the network infrastructure.

For example, when more energy is generated than necessary, Smart contracts can be built to ensure that excess energy is delivered in stock automatically.

In contrast, stored energy could be used whenever energy production is insufficient. so the blockchain technology could directly control network flows and storage structures.

Smart contracts could also be used to manage balancing activities and virtual power plants. Through the IoT and smart meters, Blockchain will manage and regulate smart grids [22].

Ideally, all transactions are made on the basis of smart contracts, i.e. based on predefined individual rules concerning quality, price, quantity etc.; decentralized transaction model with no need for third-party intermediaries, without broker.

The transaction is based on RESCoin (Renewable Energy Sources Coin), see fig.11, deriving from the production of Prosumers, which can thus exchange energy with neighboring customers for the reduction of energy transport losses.

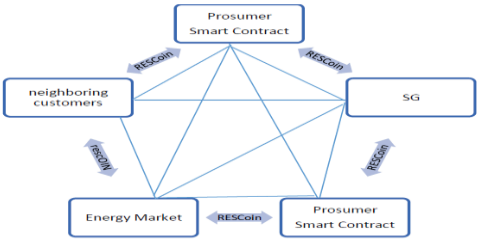

Fig. 11: Blockchain transaction model

The integration of blockchain technology in the area of smart devices, which communicate with each other and with other devices outside the Smart Home, will be necessary to have a means of communication able to transmit and store related information and transactions.

The blockchain technology can be used by Prosumers in order to obtain the reading and billing of the meters in relation to their smart meters. One of the main advantages of a blockchain-based transaction model is that all electricity delivered to networks can be attributed to individual customers in small time units (a few minutes). This means that all the electricity produced and consumed can be adjusted very precisely to precious variables. Physical electricity as such would continue to flow to the end user directly from the nearest generator, without the need for intermediaries and/or power losses.

V. CONCLUSIONS

Prosumers are valuable tools for a sustainable solution and a more efficient use of the Smart grid. They can directly use wind and solar energy and substantially reduce the amount of energy taken from the grid by reducing transport losses. Furthermore, Prosumers, through the batteries of their electric vehicles, can offset the volatility of wind and solar power production. However, if not managed through dynamic control algorithms, there will be high peaks in unsustainable demand.

In this way the energy market would not be sustainable.

Therefore, with this paper the type of network has been determined, for which the energy market system can be determined, which through smart metering will be able to manage the loads appropriately, also through delays or reduction of the load itself or by inducing aware behaviors for Prosumers, in order to manage the objective function of maximum economic return. These transitions must be dealt with safely and thanks to the Blockchain without brokers but directly by Prosumers. In contrast, stored energy could be used whenever energy production is insufficient. so the blockchain technology could directly control network flows and storage structures. Smart contracts could also be used to manage balancing activities and virtual power plants. Through the IoT and smart meters, Blockchain will manage and regulate SG and energy market.

Acknowledgment

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REFERENCES

[1] M. Kahlen, W. Ketter, J.Van Dalen Balancing with electric vehicles: a profitable business model, *Twenty Second European Conference on Information Systems, Tel Aviv 2014.*

[2] Briefing, N. N. o. u. (January 2007). "Decentralised Energy Power for the 21st Century." from http://www. mng.org. uk/gh/resources/no2n_ decentralised _energy. pdf.

[3]. Pierluigi Mancarella, D. P. (2009). Modelling of microgrid evolution and replacement profiles of EU network infrastructure.

[4] E. Nyholm, "Can Demand Response Mitigate the Impact of Intermittent Supply?," in *Systems Perspectives on Renewable Power*, ed.1.1. Gothenburg, Sweden: Chalmers University of Technology, 2014, pp. 108-118.

[5] ENTSO-E. Demand Side Response Policy Paper. 2014 Available: https://www.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/140915_DSR_Policy_web.pdf. [Accessed: 2015-12-07]

[6]M.D. Galus, G. Andersson, Demand management of grid connected plug-in hybrid electric vehicles (PHEV). In: 2008 IEEE energy 2030 conference; 2008. p. 165–72

[7] The use of intelligent trading agents (Ramchurn et al., 2011a, Ramchrun et al., 2011b, Vytelingum et al., 2011, Gottwalt et al., 2011)

[8] Ketter, W.; Collins, J.; and Reddy, P. 2013. Power TAC: A competitive economic simulation of the smart grid. Energy Economics 39:262–270.

[9] Ketter, W.; Peters, M.; and Collins, J. 2013. Autonomous agents in future energy markets: The 2012 Power Trading Agent Competition. In Association for the Advancement of Artificial Intelligence (AAAI) Conference Proceedings, 1298–1304.

[10] *Investigating the Effects of Dynamic Demand Side Management within Intelligent Smart Energy Communities of Future Decentralized Power System* A. Fazeli, E. Christopher, C. M. Johnson, M. Gillott, M. Sumner

[11] A model for generating household electricity load profiles Jukka V. Paateron,y and Peter D. Lund INTERNATIONAL JOURNAL OF ENERGY RESEARCH Int. J. Energy Res. 2006; 30:273–290

[12 Determinants of high electrical energy demand in UK homes: Appliance ownership and use Rory V. Jones, Kevin J. Lomas b Journal Energy and Buildings 117 (2016) 71–82

[13] Understanding electricity consumption: A comparative contribution of building factors, socio-demographics, appliances, behaviours and attitudes Gesche Huebner a,⇑ , David Shipworth a , Ian Hamilton a , Zaid Chalabi b , Tadj Oreszczyn, Journal Applied Energy 177 (2016) 692–702

[14] http://www.eerg.it/resource/pages/it/Progetti_-_MICENE/compendio_misure_consumi_elettrici.pdf

[15] I. Richardson, M. Thomson, D. Infield, C. Clifford *Domestic electricity use: a high-resolution energy demand model*. October 2010 Energy and Buildings 42(10):1878-1887 DOI10.1016/j.enbuild.2010.05.023

[16] Joakim Widen *, E. W. (2010). "A high-resolution stochastic model of domestic activity patterns and electricity demand." APPLIED Energy and Buildings 87 1880-1892.

[17]Y. Yan, Y. Qian, H. Sharif, D. Tipper A survey on smart grid communication infrastructures: motivations, Requir. Chall. IEEE Commun. Surv. Tutor., 15 (1) (2013), pp. 5-20].

[18] F. ClevelandCyber security issues for advanced metering infrasttructure (AMI) 2008 IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy in the 21st Century (2008)]

[19] M.P. McHenryTechnical and governance considerations for advanced metering infrastructure/smart meters: technology, security, uncertainty, costs, benefits, and risks, Energy Policy, 59 (2013), pp. 834-842]

[20] C. Lazaroiu, M. Roscia, “Smart District through IoT and Blockchain” ICRERA’18

[21] H. Jaakkola; j: Henno; J. Makela; B.Thaleheim; “Today is the future of yesterday; what is the future of today?” 40th International Conventional on Information and Communication Technology, Electronics and Microelectronics (MIPRO), IEEE 2017

[22]Karnouskos S., Nass de Holanda T., “Simulation of a Smart Grid Citywith Software Agents”