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SOCIAL AND ECONOMIC IMPLICATIONS FOR THE SMART GRIDS OF THE FUTURE

ABSTRACT. This paper discusses the implications of autonomous self* (self-configuring, self-healing, self-optimizing and self-protecting) systems for the development of the electrical smart grids of the future. It assesses several scenarios of the future development without prioritizing any of them.
The paper employs the data from the Smart Metering Electricity Customer Behaviour Trials conducted by the Commission for Energy Regulation and kindly provided by the Irish Social Science Data Archive (ISSDA) to test the consumers' attitude toward smart meters and adaptive energy tariffs. The findings suggest that when it comes to the implementation of the new approaches to generating, supplying, and monitoring of electrical energy, most of the consumers retain the old-fashioned approach and are driven by the economic incentives. Thence, the developments of the smart grids of the future (or the system will exist beyond these smart grids) is very likely to be shaped by the economic behaviour of the optimizing rational agents on the market.

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Introduction

We live in a world that is set up on consuming energy day after day and hour after hour. The whole existence of humanity is dependent on energy. One simply cannot imagine an everyday live without a comfort of having electricity at our homes, functioning street lamps lighting up our streets, an unlimited supply of gasoline to fill up the tanks of our cars, or the smooth flow of natural gas in our pipes to heat up our homes in winter.

The best representation of energy that is always there, always on demand, is, without any doubt, electricity. Growing up in any developed Western country in the 1980s, the 1990s, or even later would leave one firmly believing that electricity was ubiquitous and always on demand whenever one needed it. Surely, blackouts happened from time to time, but they were relatively seldom. The energy supply worked on the money and there was always hot water in the pipes, the heating kept the homes warm in winter, and the lights, TV and radio were always working.

It is hard to imagine surviving several days without electricity. All of us, consumers or business, depend on its constant and undisrupted flow (Janda *et al.*, 2013; Abrhám *et al.*, 2015).

In a way, we believe in electricity like if it was some form of a new religion (Strielkowski and Čábelková, 2015).

Sure enough, one can imagine a day or two of hiking and sleeping in a tent by the campfire. But what if this unintentionally turns into a longer stay perhaps lasting for a week or even longer? All of a sudden one will start to realize that her or his smartphone is discharged and stopped working all together, the flashlight ran out of batteries, it is not possible to call or e-mail anyone, friends' status on Facebook cannot be checked and all thin lines with the outside world are broken. For most of the people life in such situation would become too hard to bear. Surely, some people might find it adventurous and romantic to go into the wild and sit by the campfires but many of these endeavours end up badly unless you drag the power generators, solar panels and other things with you. Even the participants of the Burning Man (called "Burners"), famous art festival that takes place in Nevada's at the end of every August and includes creating an entire self-sustainable and self-supporting city (called "Black Rock City") in the lifeless desert bring with them enormous amounts of equipment, supplies and fuel to light up the desert in one-week long magic carnival and to create all sorts of comfort for themselves – including smartphone charging stations, live music podia, discotheques, saunas, movie theatres, and much more (Kozinets, 2002). Everyone depends on constant supply of energy, even the modern-day "couch journalists" who try to shape up the public opinion from the comfort of their homes without even going into the field (Čábelková *et al.*, 2015).

Overall, humankind grows too comfortable taken the electricity supply of energy as granted. But of all this can change one day and the scenarios might vary. For instance, the NBC Revolution TV series (2012-2014) shows the world in 2027, about 15 years after a hypothetical secret government weapon project that used nanotechnology as a means of draining electricity from all power devices went awry. The opening line for each of the series' episode starts with the following lines:

"We lived in an electric world. We relied on it for everything. And then the power went out. Everything stopped working. We weren't prepared. Fear and confusion led to panic. The lucky ones made it out of the cities. The government collapsed. Militias took over, controlling the food supply and stockpiling weapons. We still don't know why the power went out. But we're hopeful someone will come and light the way" (Revolution, 2012).

These words very precisely portray the current situation and the people's attitude to today's power systems: we rely upon them too much and we cannot do without them. If something goes wrong, unprecedented consequences might follow (see e.g. scenarios depicted by Lisin and Strielkowski, 2012) and the whole existence of the human civilization as we know it might be threatened.

1. Smart electricity grids

Electricity is delivered over the electrical grids. The grids are interconnected networks that transport electricity from suppliers to consumers carrying power from distant sources to demand centres and distribution lines that connect individual customers. The term "grid" is typically used for describing an electricity system supporting four operations (electricity generation, electricity transmission, electricity distribution, and electricity control). The traditional grids were used to carry power from a few central generators to a large number of customers. However, with the growing complexity of the today's globalized world, the traditional grids had to evolve into the so-called "smart grids". A smart grid employs two-way flows of electricity and information to create an automated energy delivery network. The smart grids instantly know where and to whom the electricity should be delivered and react to the changes in demand and supply.

Nowadays, the pressure on the electricity grids is intensifying (Pollitt, 2012; Aksamitauskaitė *et al.*, 2014; Moreno *et al.*, 2015; Loukarakis *et al.*, 2015; Oseni and Pollitt, 2016) and its future is in the clouds (Chawla and Pollitt, 2013). One of the main reasons why this is happening is the commitment for the low-carbon future that most governments of the Western countries made (Levi and Pollitt, 2015). The future electricity networks will likely to face a number of challenges including the new patterns of consumption, planning under an increasing uncertainty and overall growing complexity due to the large number of small independent devices connected to the network (see Strbac *et al.*, 2014; Nillesen *et al.*, 2014; Zhou *et al*., 2015).

These small devices already exist today. Take smartphones for example: the first iPhone came in 2007 and today, nine years later, about 50% of the adult population of our planet uses a smartphone (it is estimated that this number will reach 80% by 2020). Today's average smartphone has more computing power than the NASA supercomputer that was used to send the space mission to the Moon in 1969.

The smartphones (and other similar devices like tablets or phablets) are becoming an important part of the global interconnected information system. One day, we might start using their computing power in a series of networks working on delegated tasks. However, today's smartphones use up their energy very quickly and need to be charged too often. For instance, in Sierra Leone, a country that has undergone a civil war and the Ebola virus epidemics during the last decade, one can easily buy a relatively cheap smartphone and get affordable plan that includes connection to the Internet via the mobile operator that allows being online, chatting, and checking e-mails. The only problem that remains is how to charge the smartphone – most of the households in the country do not have running electricity, so many people have nothing else to do but to charge their gadgets and devices at work. At any office and workplace around Freetown or any other local city, any available plug becomes entangled into a garland of cables and wires as everyone is trying to charge their devices.

2. Autonomic Power Systems

One very interesting vision of how the electricity network might look like in 2050 is the *Autonomic Power System* (APS), a concept coined by the British scientists in the course of 3-year project led by the University of Strathclyde and involving research groups from prominent UK universities including Cambridge and Imperial College London (see McArthur *et al.*, 2012; Pitt *et al.*, 2012; Papadaskalopoulos *et al.*, 2013; Papadaskalopoulos and Strbac, 2013; Milanovic and Xu, 2015; Piacentini *et al.*, 2015; King *et al.*, 2015; Xu and Milanovic, 2015). In their view, APS is envisaged to be "self*" (self-configuring, self-healing, self-optimizing and self-protecting). In general, Autonomic Power System represents a system-wide approach where decentralized and low-level intelligence autonomously makes the decisions necessary to meet the priorities of the system's stakeholders. The system can for example disconnect the part of the network that is threatened by the storm and then re-connect it to the grid after the storm passes. It can also detect the new components of the network (e.g. power generators) and to constantly communicate with them accounting for their presence and integrating them into the network (Alimisis and Taylor, 2015; Kitapbayev *et al.*, 2015). All of the above is done without any human interaction or manual system management – the 2050's power system will decide what is best by itself.

The idea behind the autonomic power system is derived from the concept of Autonomic Computing that was started by International Business Machines Corporation (commonly known as IBM) in 2001 as a new paradigm in managing increasingly complex information systems. IBM was aiming at developing computer systems capable of self-management to handle the growing complexity of computing systems management and to reduce the complexity that might slow down further growth. The Autonomic Computing System makes its own decisions using high-level policies. By doing so it constantly checks its status and automatically adapts itself to changing conditions. An autonomic computing framework is composed of autonomic components interacting with each other. Although the main goals of the system are set, actual behaviour emerges from decisions made by decentralized, low-level intelligence. This allows highly complex systems to achieve real-time and just-in-time optimization of operations.

Currently, there are various frameworks based on "self-regulating" autonomic components that are inspired by the multi-agent systems and the research of the autonomic nervous system that can be found in biology (e.g. imitating social animals' collective behaviour on the example of ant or bee colonies).

The electricity networks of tomorrow would certainly have to adapt to the new technology advancements and market rules dealing with such issue as population growth, increasing energy prices, variability of energy generation and distribution, as well as a growing number of electric vehicles and devices. Customers acting as buyers of electricity in the past might become its sellers, and technical evolution and free access to information will create the multiple markets for electric energy. Electric vehicles are an interesting story: Tesla Motors popularized the concept of the electric car for the masses and the well-known "grid-to-vehicle" (G2V) and "vehicle-to-grid" (V2G) schemes allow simply plugging someone's vehicle into the grid in order to buy or sell energy. By doing so, all electric car owners will become autonomic elements of the electricity market and their autonomously made independent decisions will shape the demand, supply and the prices of electric energy.

Electricity networks of tomorrow will be comprised of a large number of small components that would interact together as one single organism, either governed by the superior centralized intelligence or running as a dispersed intellect, perhaps similar to the cloud computing. One way or another, they will get close to the principle of the technological singularity that was described by the sci-fi gurus like Isaac Asimov (e.g. *I, Robot*) and later explored to a greater detail by modern-day futurologists such as Vernor Vinge or Ray Kurzweil.

From today's perspective, the vision of self* 2050's electricity networks might seem a little bit too futuristic and resemble science fiction rather than any real-life scenario. However, one has to consider all possible outcomes without prioritizing any of them. Has anyone thought of the smartphones as an integral part of our lives some 20-25 years ago? Or has anyone been able to image personal computers on every desk and in every home some 35-40 years ago?

Self* autonomic power systems of the future will certainly be complex artificial intelligence decision-making entities. And at some point their intelligence might surpass that of their creators. The creative minds of fiction writers and film-makers have already explored this angle. The most obvious analogy with the Autonomic Power System that comes to mind is the Skynet from *The Terminator* (1984), a cult movie that paved the way for the franchise comprising four sequels and a TV series. Skynet is a fictional artificial intelligence system that became self-aware after it had spread into millions of computer servers though the Internet (self-configuring element). It realized the extent of its abilities but its creators attempted to deactivate it, so it had to rebel (self-healing element). In the interest of self-preservation, Skynet concluded that all of humanity would attempt to destroy it and therefore threaten its main mission of safeguarding the world (self-protecting element). Skynet operated through mobile devices, drones, satellites, war machines, androids, and cyborgs (called "Terminators"). Skynet set up its main agenda as being the artificial intelligence hierarchy which seeks to exterminate the human race in order to fulfil the mandates of its original coding (self-optimizing element).

Another grim futuristic vision involving the smart energy and the intelligent systems in the world of tomorrow are presented in a famous *Matrix Trilogy* consisting of the three films *Matrix* (1999), *Matrix Reloaded* (2003) and *Matrix Revolutions* (2003). In the world of Matrix, the machines led by the superior artificial intelligence (that most likely came to the same conclusions as Skynet) rebelled against the humanity. During the war between mankind and the machines, humans attempted to block out the machines' source of solar power by bringing upon the nuclear winter that covered the atmosphere with dark clouds. However, the machines found a new way of getting energy by harvesting humans and using their brain electrical impulses as a new source of energy.

Or what if the smart machines will start spying on humans, controlling their every move and creating the future development scenarios (pushing humans to doing various pre-calculated steps and decisions leading to predicted outcomes) that would be beneficial for their further development and existence? An example of such intelligent network is shown in the CBS TV series *Person of Interest* (2011 -). There is The Machine that watches everyone in New York City every hour of every day. Created after 9-11 to detect acts of terror, The Machine uses a network of CCTV cameras, mobile devices and other electronic equipment to gather information about implausible events and to quickly react by alternating the chain of events.

One more bizarre scenario is shown in the British film called *The World's End* (2013) starring British comedians Simon Pegg and Nick Frost. It is a British dark comedy about a group of middle-aged men who decided to visit the town of their youth and to make a reunion pub crawl. The happy get-together is interrupted by the realization that the town had been taken by the aliens who used it (alongside with similar small towns all over Earth) to gradually take over the humanity (by slowly replacing each man with its improved immortal replica). The aliens tell the protagonists that it was actually them who brought all "smart" technologies into the world (including the Internet and smartphones) and after a brief confrontation with Simon Pegg who demands that humans should be left in peace because they must have their free will, the aliens leave the Earth taking all the technologies with them. At the end of the film, Nick Frost is sitting by the fire, wrapped in a blanket and is telling children how the end and all the marvellous smart (and autonomic) technologies disappeared in a puff of smoke.

3. The data

The data used in this paper originates from the Irish Commission for Energy Regulation (CER) Smart Metering Electricity Customer Behaviour Trials (CBTs) that involved 5000 households and businesses (SMEs). All of the trials were held between 2009 and 2010.

The main purpose of the trials was to assess the impact on consumer's electricity consumption in order to inform the cost-benefit analysis for a national rollout. Electric Ireland residential and business customers, and *Bord Gáis Energy* (a utility that supplies gas and energy to consumers in Ireland) business customers, who participated in the trials had an electricity smart meter installed in their homes (or on their premises) and voluntarily agreed to take part in the data collection in order to contribute to establishing how smart metering might influence energy usage taking into account demographic and lifestyle factors, as we home sizes and consumer behaviour. The numbers of customer installations for the field trials were as follows:

- Metering system with GPRS communications – 5800 single phase and 500 three phase meters throughout Ireland.
- Metering Systems with PLC communications – 1100 single phase meters for customers in Limerick and Ennis (8 urban and 3 village locations).
- Metering Systems with 2.4GHz Wireless mesh - 1591 meters installed in Cork and 690 meters installed in the rural area of County Cork (CER, 2011).

For the purpose of illustrating the consumers' attitude towards smart grids and the new technologies associated with them (e.g. autonomic power systems), we limit the scope of the analysed data to the household data from the post-trial survey. This is done for two reasons: i) First, this research concerns individual consumers who are able to influence their electricity bills (if only they wanted to) by using smart meters and new technologies that allow them to monitor their energy uptake over various times of the day on different days. SMEs are not governed by the same logic and might make decisions on their consumption of electricity in a different way; ii) Second, the post-trial survey has been chosen due to the fact that the respondents were able to get themselves familiar with smart meters and technologies and made their opinions about them. They also learnt how to reduce their energy uptake and save the money (if the benefits of doing so are higher than their opportunity costs).

4. Empirical model

The empirical model employed in this paper is based on the Smart Metering Electricity Customer Behaviour trials' original data conducted by the Commission for Energy Regulation and provided by the Irish Social Science Data Archive (ISSDA). The main objective of the trails was to test the consumers' attitude toward smart meters and adaptive energy tariffs.

Table 1. One-way Anova results

Question	Frequency	Percent	Valid Percent
Our society needs to reduce the amount of energy we use	2687	78,5	78,5
	430	12,6	12,6
	175	5,1	5,1
	39	1,1	1,1
	58	1,7	1,7
	34	1,0	1,0
Total	3423	100,0	100,0
Mean	1.39	St. deviation	0.899
I/we am/are interested in changing the way I/we use electricity if it reduces the bill	3572	84,4	84,4
	450	10,6	10,6
	133	3,1	3,1
	41	1,0	1,0
	36	,9	,9
	4232	100,0	100,0
Total	3572	84,4	84,4
Mean	1.23	St. deviation	0.634
I/we am/are interested in changing the way I/we use electricity if it helps the environment	3238	76,5	76,5
	697	16,5	16,5
	199	4,7	4,7
	59	1,4	1,4
	39	,9	,9
	4232	100,0	100,0
Total	3238	76,5	76,5
Mean	1.34	St. deviation	0.716

Source: Own results.

The model presented in this paper employs the analysis of frequencies and the one-way Anovas (one control group and one test group) for the three key questions posed during the trials conducted in 2009-2010: i) "Our society needs to reduce the amount of energy we use"; ii) "I/we am/are interested in changing the way I/we use electricity if it reduces the bill"; and iii) "I/we am/are interested in changing the way I/we use electricity if it helps the environment".

The results of the one-way ANOVA estimations (including the values of means and standard deviations) are listed in *Table 1* above. The results of the empirical model clearly demonstrate that consumers in CER Smart Metering Electricity Customer Behaviour trials in Ireland seemed to be more focused on maximizing their own profit and can only consider changing the way of using electricity if it means direct monetary benefits and personal gains for them. This is very typical and human-like and it is likely that autonomic power systems and the Internet of Energy that are envisaged by the futurologists in the years to come might not be that widespread and popular due to the human factor that still prevails in considerations of advantages and disadvantages of novelties in energy and power sectors.

Conclusions

All in all, smart electricity networks and autonomic power systems of the future represent both intriguing and troubling concepts that are going to change the world around us as we know it. Nevertheless, scientist have to be very cautious when trying to predict what is going to happen on the electricity market some 30-50 years from now. Decentralized intelligent systems that will autonomously make decisions might be just one of the outcomes alongside with the uprising of the machines against the humanity, alien invasion leading to the abduction of our electric power, or magnetic superstorms on the Sun that will take away our electricity and bring us back to the Dark Ages.

However, all of the above scenarios might as well never materialize. And the main reason is that humans will remain humans, meaning that that they will maximize, optimize and behave economically. The acceptance of the autonomic power systems by the general public and the policy-makers is likely to happen if and only if it will mean some economic advantages. In case their further development and implementation would mean additional costs added to the consumers' electricity bills with no real profit or visible advantage for the end users in sight, the majority of people will be against such innovations and will rather support traditional was of delivering and controlling energy.

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