A COMPARATIVE STUDY OF SMART GRID DEVELOPMENT IN DEVELOPED AND DEVELOPING COUNTRIES

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Abstract

During recent years, there has been an increasing interest in the potential opportunities that can be attained with the use of smart devices in order to gather data or automate processes. This type of communications between devices with minimal human intervention is referred to as Machine-to-machine (M2M) communications that can be applied to optimize resources and improve service delivery applications. Smart Grid is one of the M2M communications applications that is attaining more attention during recent years, because of its potential to change the complete energy ecosystem; going from a unidirectional system to a bidirectional one where customers will have an important role in the ecosystem.

Depending on the country and its characteristics and situation, Smart Grid development can be very different. This article identifies commonalities and differences in Smart Grid communication development considering the current status in developed and developing countries. The process is done by evaluating the following techno-economic aspects: Technology development, Public initiatives, Regulator policies and Economic situation/Business perspective of the country. The article is concluded by showing that regulator policies regarding the level of liberalization in the energy market are a key element when defining business strategies and different stages of Smart Grid communications development has a critical influence in the definition of business models, as it defines the key activities, partners and value proposition for the business.

Keywords

Machine-to-Machine Communications; Smart Grid; Techno-Economic Analysis

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1. Introduction and motivation

During recent years new technologies and services based on Machine Type Communications (MTC), also referred as Machine to Machine (M2M) communications have appeared in different sectors like healthcare, transport, logistics, media and utilities; where MTC is usually defined as the kind of communication between devices with minimal human interaction. Although MTC has started to be implemented in recent years but in the future will have a major impact in the society in many different aspects: financial benefits, efficient resource management and potentially changing every single way we interact with our city and society. As an instance, a major effect on of MTC on big telecom actors' agenda can be observed by Ericsson´s vision of a "Networked society" where everything that can benefit from a connection will be connected and there will be over 50 Billion Machine to Machine (M2M) connections by 2020. [1]

One of the applications for M2M is Smart Grid, which is the concept of having connection over the complete electric Grid in order to be able to monitor, manage and control its state [2]. The Smart Grid here is considered as a combination of all the service connections, transformers, transmission infrastructure, substations, generation plants, and everything required to manage the generation and distribution of electrical power [3]. The successful development and implementation of Smart Grid technologies has the potential to change completely the way energy systems are managed, from generation to the final customer and enabling an efficient usage of energy in cities and homes. In this development, communication technologies and specially M2M communications are playing a major role, as Smart Grid services need communication networks to fulfil specific requirements.

In this context many Smart Grid initiatives have been started in recent years usually driven by governments or public institutions, as utility sector is usually a highly regulated market. This situation leads Smart Grid development to a situation where its state can differ in many ways between different countries and different areas. Therefore, the goal of this paper is to analyze and show the differences and commonalities between developed and developing countries regarding Smart Grid communication development.

- What are the commonalities for Smart Grid communications development in developing countries? And in developed countries?
- What is driving Smart Grid communications development in developed countries? And in developing countries?
- How can the different Smart Grid communications development affect business strategies for utilities in different countries?

2. Methodology and work flow

This study is done by a dual qualitative/quantitative analysis based on a literature review, information from industry partners (i.e. Ericsson and Siemens) and information from public institutions such as World Bank, National and European governments and the International Energy Agency. Four countries have been chosen (Australia, Sweden, Brazil and China); two developed and two developing, with the goal of considering countries in different geographical areas and different context. These specific countries are selected in order to consider countries with different situations and aiming to have a holistic view on Smart Grid development in developed and developing countries.

The study focuses on four major topics: Technology development, Public initiatives, Regulator policies and Economic situation/Business perspective of the countries. These four topics have been chosen in order to provide a holistic understanding of the Smart Grid development and future perspective, by considering technological, regulatory and economic/business aspects.

Technology development will be assessed considering Smart Metering penetration and the number of relevant pilot projects classified in five categories: Smart metering, Integrated systems, Home applications, Transmission, Distribution automation and Others. This classification is based on the framework initially defined by Virginia Tech Clearing House defined and used together with the JRC (Joint Research Centre - European Commission) in order to define Smart Grid assessments methods [4] [5]. The goal is to be aware of different stages of the Smart Grid development in developed and developing countries and try to identify common aspects and trends. Public initiatives will be assessed by surveying the existence of public plans or roadmap for Smart Grid development and the motivations and/or drivers behind this development. By understanding the Smart Grid drivers we will are able to understand the different ways of developing the technologies and the different approaches that may be selected depending on the motivation.

Regulator policies are a key aspect to consider when working with Information and Communication Technologies (ICT) in the energy sector, as usually energy sector is highly regulated in all countries. In order to understand the regulator policies in different countries two factors are considered: the relation between public and private actors in the generation and distribution side and the level of liberalization in the retail market. Economic situation/Business perspective of the country will be considered in order to obtain useful insights on the situation of each country and relate them to the other aspects considered in this paper. By making this connection we will be able to identify the implications between the economics and development of a new technology like Smart Grid.

By analyzing the four aforementioned aspects we will be able to understand and provide conclusions on the status of Smart Grid in the chosen countries and its future perspective. In addition to that, common trends and characteristics in the considered countries will be identified and analyzed.

3. Comparative study Smart Grid development: developed and developing countries

In order to provide a holistic description of Smart Energy situation we would go through four different aspects: Technology development, Public initiatives, Regulator policies and Economic situation/Business perspective of the country. For each of the four aspects considered, relevant information will be gathered and analyzed in detail.

The countries considered are: Australia, Brazil, China, and Sweden. These countries have been selected with the aim of providing a global view on Smart Energy development, considering developed (Australia and Sweden) and developing (China and Brazil) countries, and countries all over the globe (Europe, Asia, Latin America and Oceania).

3.1. Technology development

The goal of gathering this data is to understand how mature the Smart Energy situation is in these four countries and its possible implications for business development.

The technology development aspect will be analyzed by considering two different items:

- Smart meter penetration. Percentage of smart meters installed.
- Relevant pilot projects divided in five categories:
    - Pilot project on smart metering. Includes projects which specifically address smart meter implementation.
    - Pilot projects on Integrated systems. Focuses on the integration of different Smart Grid technologies and applications, for example projects including smart metering and substation automation.
    - Pilot projects on Home Application. Includes projects which address new applications at home or directly involved users.
    - Pilot projects on Transmission and Distribution automation. Refer to projects dealing with automation upgrades of the electricity grid, at the transmission and distribution level.
    - Pilot projects on Others. Refer to projects that are not specifically focuses on Smart Grid but including the test of one or more capabilities related with Smart Grid technologies or services. Examples of this kind of projects are smart city, renewable energy or electric vehicle projects.

The classification of relevant pilot projects used is based in the framework initially defined by Virginia Tech Clearing House and EUUS council, within this initiative JRC (Joint Research Center- European Commission) is collaborating with the US Department of Energy on common assessment methodologies of Smart Grids. In this table there are only considered Smart Grid relevant projects from ”Smart Grid 2013 Global Impact Report”. [4] [5]

Table I Technology development

Technology development	Australia	Sweden	Brazil	China
Smart meters installed	23 %	100%	7,5 % (2014 prediction)	27%
Nª of pilot projects	12	5	12	11
Pilots projects on Smart Meters	2	0	6	3
Pilots projects on Integrated Systems	2	4	6	2
Pilots projects on Home Application	1	0	0	0
Pilots projects on Transmission and Distribution Automation	0	0	0	4
Pilots projects in Others	7	1	0	2

Australia. Smart Meters are fully deployed in Victoria state, while the deployment in the rest of the country is very reduced reaching only a 23% overall penetration. The pilot projects performed show the maturity in the field of Smart Metering and the interest in projects related with Renewable Energy, focusing on solar generation. [6]

Sweden. The country is one of the early-adopters of Smart Grid technologies and is working to continuing to be a reference in the field. Sweden has a well-developed energy market and customers concerned about environment and the usage of renewable energies. Smart Meters in Sweden are already deployed and there is a plan for a 2nd generation of Smart Meters. The pilot projects done show how the country is focusing in testing Integrated systems and not only isolated parts of the Smart Grid. [7]

Brazil. Smart Meters are in its first deployment stages and by the end of 2014 is expected to reach only 7,5% penetration and 75,3% in 2030. This shows the limited deployment of Smart Grid technologies in the country and the great potential and work that needs to be done in the future in Brazil. Regarding pilot projects Brazil is mainly focus on smart metering, as one of the motivations is avoid fraud in the power grid. The pilot projects performed support the statement that Brazil is in its early stages of Smart Grid development and presents important business opportunities in the field. [8]

China. Smart meters are now being deployed massively in China by SGCC (State Grid Cooperation of China) and the current percentage of Smart Meters deployed is 27% (Siemens). The pilot projects performed show special activity and leadership on Transmission and Distribution Automation, this is due to the challenges China is facing when it comes to its Power Grid usage. Chinas Power Grid is having problems on growing at the same level as the industry is

growing and therefore improving Transmission and Distribution efficiency and control is a clear goal for China´s Power Grid.

3.2. Public initiatives

The goal of considering public initiatives is to understand what are the motivations and drivers for Smart Energy in every country, which will be different and have implications when analyzing Smart Grid development and defining business strategies. In this table two aspects are show: the presence or not of a Smart Grid Public program and the main motivation for each country to the adoption of Smart Grid technologies.

Table II Public initiatives

Public initiatives	**Australia**	**Sweden**	**Brazil**	**China**
Smart Grid Public programs	Yes	Yes	Yes	Yes
Main motivation (s)	Renewable energy and Energy efficiency	Renewable energy, improved services and energy efficiency.	Development of the power grid, energy efficiency and avoiding fraud.	Renewable energy, development of the power grid state and energy efficiency

Australia. Australia has been active in Smart Energy since 2004 in the context of energy reforms related with renewable energy and energy efficiency. The federal government has been responsible of coordinating a framework under which Smart Energy policy will be done and state institutions are the responsible of smart meter rollout and pilot projects. The more active state in terms of Smart Energy activity has been Victoria with the biggest pilot projects and smart metering deployment. In the case of Australia is important also to point out the presence of a National Broadband Network, which aims to provide fiber optic connections to 90% of Australian homes and businesses. This program has the potential to be a key enabler of Smart Energy in Australia. The main drivers identified for the Australian case have been Renewable Energy and Energy Efficiency [9] [10] [11] [12].

Sweden. Sweden, as in many other technologic fields, is one of the most advanced countries when talking about Smart Grids. In 2009 the legal demand of the deployment of Smart Meter rollout was done. Smart Grid initiatives in Sweden are fully supported by the institutions and these efforts make it easy the development of several demonstration projects like Smart Grid Gotland project or Stockholm Royal Seaport. The main drivers for the evolution of Smart Grids in Sweden are Renewable energy, improved services (like hourly meter reading) and energy efficiency [13] [7].

Brazil. Brazil has been active since the definition of a National Smart Grid program defined by the ANEEL (Agencia Nacional de Energia Eletrica) which address the basic aspects of Smart Grid technology adoption, like definition of R&D programs, definition or modification of laws

and regulation and identification of deficiencies in the current grid. The main drivers identified for the Brazilian case have been Development of the Power Grid, Energy Efficiency and avoidance of fraud. The reason behind these drivers is the need of Power Grid development due to the growth on electricity consumption caused by the economic expansion of the country. [14]

China. China has a national plan to define Smart Grid standards: SGCC (State Grid Corporation of China) Framework and Roadmap for Strong and Smart Grid Standards. In this plan SGCC expounds the formulating principles, concept model and overall structure of the standard framework, and puts forward a smart grid standard framework and roadmap suitable for Chinas national characteristics. China is facing crucial energy challenges (supplying the amount of energy required to the growing industries, reducing contamination levels and improving reliability of the electricity network) that define Renewable energy, Development of the power grid state and Energy efficiency as the main drivers for the development of the Smart Grid in China. This strong drivers and the capability of China to define country policies in a unified way put the country as one of the future leaders in the Smart Grid field. [15] [16].

3.3.Regulator policies

One of the characteristics of energy sector is that usually it is highly regulated market defined by public regulations and governmental policies. Therefore in order to understand the different market situations is important to consider the different regulator policies.

As there is no framework previously defined to analyze regulator policies, we have decided to consider the level of liberalization of the sector and the ratio between public and private market shares. The aspects considered are: market power shares private/public and Herfindahl index in Generation and Distribution sector and qualitative description of the retail market. Herfindahl index is used to measure the level of competition in a market, high values mean low competition and low values mean high competition.

By doing this analysis two type of conclusions can be obtained. Firstly, markets with a high level of competition will require higher levels of innovation and therefore business opportunities for Smart Grid will appear. Secondly, markets highly liberalized will be more open for new actors to enter and this is a key factor for Smart Grid development.

Table III Regulator policies

Regulator policies	Australia	Sweden	Brazil	China
Market Power shares (public vs private)	Generation: 90-10 Distribution: N/A	Generation: 66-34 Distribution: N/A	Generation: 90-10 Distribution: 36-64	Generation: 96-4 Distribution: 100-0
HHI Index Herfindahl	Generation: 3147 Distribution: N/A	Generation: 2569 Distribution: 621	Generation: 1085 Distribution: 655	Generation: 306 Distribution: 6400
Retail	Full competition	Full competition market	Free-trade environment	No competition market

Australia. Data available from Australia shows that generation is mainly control by public companies which own 90% of generation assets; the HHI shows this situation with a value of 3147 over 10000. To understand this value is important to point out that the energy policies are divided in states and every state has its own generation companies. In addition to that, every state can have more than one public generation company reducing the market shares between them. Regarding the retail market is a full competition market where any private company can enter in the business. Despite this full competition market is important to point out that in some states companies are trying to become vertical and control from generation to retail. [17]

Sweden. Generation sector is mainly controlled by public companies with around 60% of market share. Regarding competition Distribution sector shows a much more competitive situation than Generation, with a HHI of 621 and 2569 respectively. When analyzing retail market we found a full competition market where entry barriers are much lower than in other countries analyzed [18] [19].

Brazil. Generation sector in Brazil is mainly control by public companies with a market share of 90% with a HHI of 1085, the low value of HHI is due to the many small public generation companies in the country. About the distribution sector it has majority of private participation with more than 60% of private market share and a very low value of HHI with 655. Regarding retail market Brazil change the structure of its retail market with the reform impulse by Lulas government in 2004, in this reform retail market became full competition market allowing and supporting the entrance of new actors and stimulating competence. This retail market is defined by Brazilian institutions as Free-Trade environment [20] [21].

China. Regarding the market regulation in China and its policies is important to highlight that market shares values and HHI are not as relevant as in the other countries studied. Is well-known that China has very specific political and economic regulations, and the energy sector is not an exception. Chinese generation sector is almost completely controlled by public companies, the country is divided in several regions and in each region a public company has the control of the generation. Therefore the HHI value of 306 is not relevant. About the distribution network is also fully control by the public institutions following a very similar pattern as in the generation sector. Regarding the retail market there no competition as the different areas have assigned a single retailer that can supply electricity [22].

3.4. Economic situation/Business perspective of the country

In this table we will try to show different aspects that are relevant in order to analyze and understand the economic situation and the business perspective in these four countries.

The information showed in this table is GDP, GDP per capita, GDP annual growth predictions 2015-2020, GDP annual growth 2003-2012, overall energy consumption, industrial energy consumption, industrial energy consumption percentage, energy consumption per capita 2009-2013 and energy consumption world rank.

The goal of analyzing this information is to be aware of the macroeconomic situation in order to identify the quality of the business opportunities that will appear in these countries and the possible implications and relations between macroeconomic characteristics and smart grid development.

Table IV Economic situation/Business perspective

Economic situation/Business perspective	Australia	Sweden	Brazil	China
GDP (billion dollars)	1,505	557	2,242	9,181
GDP per capita (dollars)	64,863	57,909	11,310	6,747
Average GDP annual growth predictions 2015-2020 (%)	2,83	2,64	1,5	6,16
Average GDP Annual growth 2003-2012 (%)	3,004	2,14	3,75	10,21
Overall Energy consumption (gWh)	1,117,222	90,160	400,000	5,256,064
Industrial Energy consumption (gWh)	432,777	38,228	150,000 (2009)	3,900,000
Industrial Energy consumption (%)	38,7	42,4	37,5	74,2
Energy consumption per capita 2009-2013 (MWh/capita)	10,55	14,03	2,44	3,3
Energy consumption world rank	17	26	10	1

Australia. Australia has a big economy with a GDP of around 1000 billion dollars and the highest GDP per capita of the four studied countries. About the evolution of the GDP annual its behavior is at in 3% annual growth what shows that Australian economy is stable and healthy. The energy consumption per capita is high (around 10 MWh/capita) and the country ranks 17th in energy consumption. As a conclusion Australia can be described as a very stable and growing economy where consumer have a high purchasing power, regarding energy consumption it is already high so there no much room for growth but it shows also that it is an interesting and profitable market to enter [23] [24] [25].

Sweden. Sweden has a small economy in terms of nominal GDP but however enjoys a very good situation in terms of GDP per capita. About the evolution of the GDP annual growth it has been stable around the 2% and the predictions show that this growth will continue in the same path. The overall energy consumption is low (logical attending the population of the country) and

the consumption per capita is the highest among the countries analyzed. The country ranks 26th in energy consumption worldwide. As a conclusion Sweden can be defined as a country with a strong economy and high purchasing power, regarding energy consumption the country has also the highest consumption per capita among the studied countries [23] [24] [25] [26].

Brazil. Brazil has a big economy with a GDP of around 2500 billion dollars and a low GDP per capita (only behind China in this study). About the evolution of the GDP annual growth Brazil have been growing between 3.4% during the last 10 years and will continue that pace until 2023. The overall energy consumption is high as the country have been developing and growing during the last years, however the energy consumption per capita is very low and there is big room for growth. The country ranks 10th in energy consumption. As a conclusion Brazil can be described as a developing economy with a fast growth evolution and with predictions of continuous development of the power grid and high consumption potential growth [23] [24] [25] [27].

China. China has one of the biggest GDP economies in the world (only behind USA) and the lowest GDP per capita of the four countries studied. About the evolution of the GDP annual growth has been growing at an average of 10% annual growth and it is expected to grow at around 6% during the next years. The overall energy consumption is very high due to the energy consumed by the industries and the energy consumption per capita very low (only at the same level of Brazil) and the country ranks 1st in energy consumption worldwide. As a conclusion can be described as big and developing economy with a fast growth evolution and with predictions of continuous development of the power grid and high consumption potential growth, especially in householder's consumption [23] [24] [25] [28].

4. Conclusions

- **What are the commonalities for Smart Grid communications development in developing countries? And in developed countries?**

Economic and Smart Grid development go together. Typically countries with a higher economic level also have a more developed Smart Grid technologies. Developed countries are in advanced levels of development while developing are commonly initial stages of development (Smart Metering rollouts).

Another similarity within developed countries is the focus on integration on renewable energies (by making pilot projects focused on it). For developing countries renewable energy is not the main focus, even though China has shown some interest.

- **What is driving Smart Grid communications development in developed countries? And in developing countries?**

Mainly driven by public policies and roadmaps. Government and public institutions are leading the development of Smart Grid. Exceptionally we detected that in some countries there is

also a huge implication from some private actors, but from a general perspective public institutions lead the way and public actors follow its guidelines.

Depending on the specific situation of the country, different motivations can be found. For instance, some countries are more focused on avoiding fraud rolling out Smart Metering infrastructure while others are aiming to integrate renewable energy in the grid or improving energy efficiency in the grid.

- **How can the different Smart Grid communications development affect business strategies for utilities in different countries?**

The different stages, drivers, regulator policies and public initiatives regarding Smart Grid communications development can have a big impact when defining business strategies. The regulator policies regarding the level of liberalization in the energy market are a key element when defining business strategies. Countries with a high level of liberalization are much more efficient attracting private investment and promoting development of new technologies.

The different stages of Smart Grid communications development has a critical influence in the definition of business models, as it defines the key activities, partners and value proposition for the business. These aspects vary depending on the needs of each market, being different for a country focused on Smart Metering rollout or in distribution and transmission automation.

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