eChallenges e-2011 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2011
ISBN: 978-1-905824-27-4

"Future Energy Grid" – Migration Paths into the Internet of Energy

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Abstract: This paper presents results obtained within the project "Future Energy Grid". The main goal is to identify technological migration paths for Information and Communication Technologies (ICT) in order to support the evolution of the power system towards a smart grid. To achieve this, three "extreme" scenarios for 2030 have been developed, adapting a scientific methodology for scenario techniques. They are being derived from a set of eight key factors, each having two to four future projections for proper scenarios. Based on these results, recommendations for regulatory, technical and political actions will be given, addressing decision makers from politics and economy. Especially, coordination between market development and political frameworks for funding and technology export shall be supported.

1. Introduction

The change of the energy industry is part of international research and political agendas, for example in Europe [1], the United States [2] or China [3]. Among other aspects the reduction of carbon dioxide emissions and a sustainable, reliable power supply shall be achieved by an enhancement of the power system[1]. This enhanced power system is often referenced as "smart grid" which may be described as an "electricity network that can intelligently integrate the actions of all the users connected to it – generators, consumers and those that do both, in order to efficiently deliver sustainable economic and secure electricity supply" [4]. It can be easily understood there are many ways to implement such a network, which can be seen as an "Internet of Energy" [5], and a high diversity within research topics concerned with the smart grid. Among other aspects there is research done regarding specific components like smart meters and smart appliances, dynamic tariffs and market platforms, communication technologies or the electrical infrastructure[2]. Since the common vision of a smart grid is based on communication technologies and software, interoperability and security are also significant topics. Moreover the complexity of the smart grid is heightened by the different political agendas and the varying preconditions within each country concerned with implementing a smart grid.

In contrast to the in detail research regarding the topics mentioned above, an overall strategy for the implementation of (or transition towards) the smart grid is still to be developed. Within the project "Future Energy Grid" technological, social and political aspects relevant for the realization of the smart grid are analyzed coherently. The work presented in this paper focuses on the evolution of the German power system until the year 2030. Many challenges arising during the migration of the existing power grid in Germany into a future smart grid have been identified by analyzing the current state of the grid and possible future shortcomings. European and worldwide development plans for the smart grid have also been considered to ensure consistent results. Technologically, ICT provide

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[1] For example see [8] for the European 20-20-20 goal.
[2] Within Germany these research topics are addressed by the E-Energy Initiative. Pilot projects are conducted within six model regions. (http://www.e-energy.de/en/)

the means to realize the smart grid and solve these issues. Therefore there is a need to identify the steps to evolve the technology used in the grid for a successful transition by the year 2030.

2. Objectives

As shown in Figure 1 recommendations for decision makers from both politics and economy provide the primary objective (highlighted as 1) of the research results described in this paper. These recommendations intend to coordinate the development of new markets and solutions in the context of the smart grid and the respective political frameworks supporting them and providing adequate incentives.

The recommendations are based on the developed migration paths of ICT in smart grids as the secondary objective (2). These paths provide a graphic description of possible ways to achieve a successful smart grid development. They focus on the development of ICT which enables the system functions needed in a smart grid context. Therefore they create awareness for the development processes concerning technology, politics and markets in respect to the smart grid for the year 2030. To develop these paths an assessment of technological groups and their stages of development is done. This also includes the state of the art deployed today. A domain model is used to allocate the technological groups to the domains of the energy system.

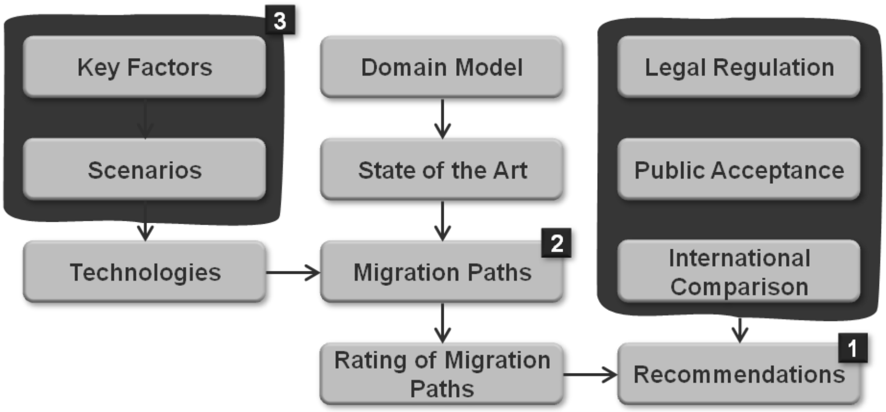

Figure 1: Objectives of "Future Energy Grid"

The key factors and the derived extreme scenarios for the smart grid create an integral outline of the smart grid and provide the “big picture” for a smart grid vision. They therefore represent the third main objective (3). The methodology used provides insight on how to address long term development processes and creating a structure for the development of adequate measures. This is substituted by the classification of the activities smart grid within the international context concerning smart grid development plans, European legislation and market analysis and the inspection of legal regulation and public acceptance issues regarding the smart grid implementation.

3. Methodology

The focus of the research presented in the paper is to determine the possibilities for the development of ICT in smart grids in Germany by the year 2030. The structure to describe the way from today’s power system to the possible states in 2030 must be able to identify critical factors which strongly describe the state of the art as well as future system architectures. On the other hand the future states cannot be precisely predicted so that the method has to support the development of different outlines of the energy system.

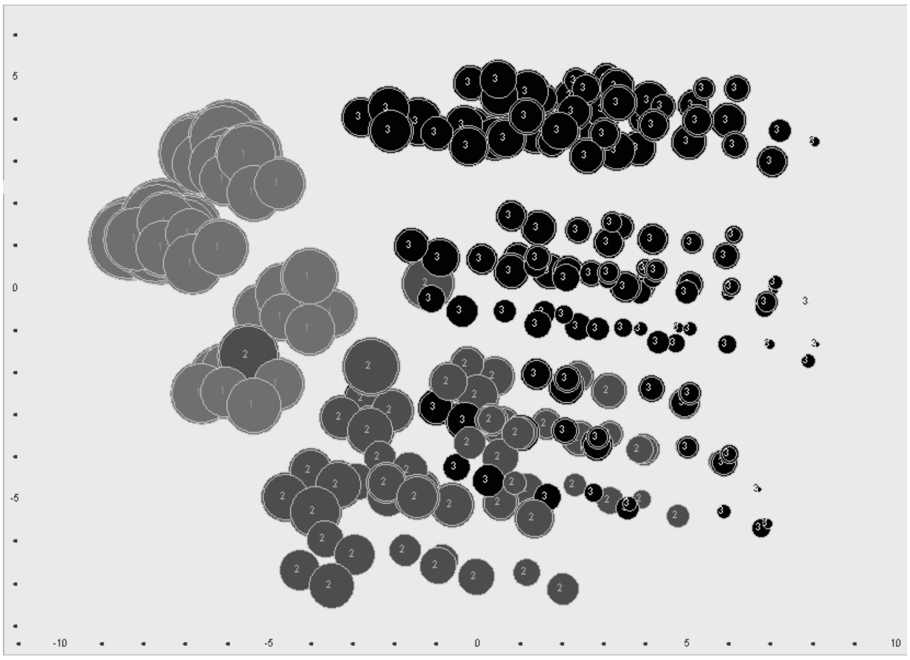

Figure 2: Identification of Scenarios by Cluster Analysis

A well established scenario technique (see [6]) was adapted to create scenarios for the power system. It was chosen due to two important characteristics. On the one hand, the methodology considers previous approaches and is under continuous development. On the other hand, it provides many possible decisions within the single developing steps to customize the methodology according the special needs of each use case. Thus, the methodology can be parameterized to fit the requirements of specific contexts. It allows identifying key factors and creating projections of these factors as snapshots in time. Using the key factors and their projections scenarios can be derived. In case of Future Energy Grid scenarios are developed which differ the most in respect to the projections of the key factors (see Figure 2). These "extreme" projections define the frame for the future energy system. The scenarios characterize the system as a whole instead of creating exact predictions regarding specific aspects. This strategic approach is also more robust regarding disruptive events like rapid, unforeseen technological progress, political change or natural disaster.[3]

The scenarios serve as the basis to outline key technologies required to implement possible versions of the future energy grid. These technologies are identified in cooperation with key players from utilities and economies concerned with the energy industry. The state of the art and future technologies analysis act as the drivers for migration path development. The rated migration paths act as the main result concerned with the ICT-deployment needed for implementing a smart grid. To obtain recommendations for decision makers in politics and economy that account beyond technological aspects the topics legal regulation, public acceptance and international developments are assessed by experts within the respective field. The factors used for the comparison are derived from the key factors for scenario development, also indicating the methodologies transferability.

4. Developments

The German power grid was analyzed regarding important influences using an established scenario technique [6]. Following the methodology depicted in Figure 3 two system levels were distinguished, "electrical power supply" itself and its "environment". There were 32

[3] For example the Tōhuku earthquake on March 11th, 2011 and the resulting accident at the nuclear power plant Fukushima 1 lead to a revalidation of expansion plans for nuclear power generation.

influence factors identified, which were allocated to the groups infrastructure, consumption and generation (system level "electrical power supply") and markets, society, technology and politics (system level "environment").

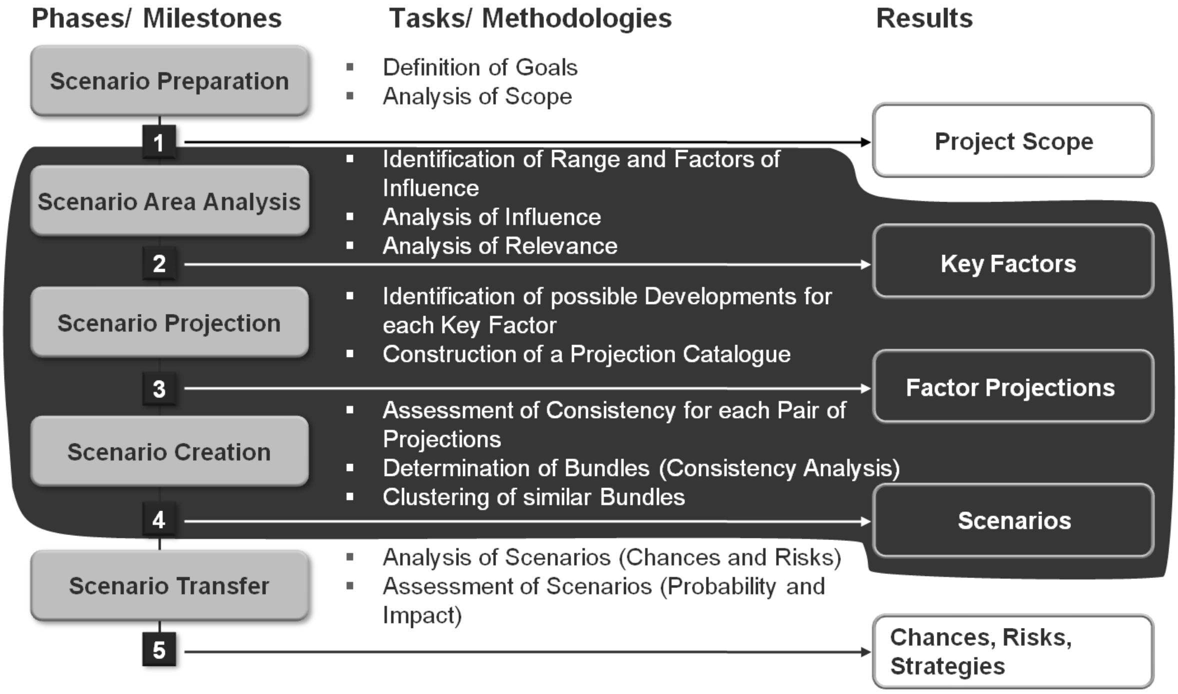

Figure 3: Methodology for the Development of Scenarios [6]

Eight key factors were selected by analyzing the interdependencies between the influence factors. The development of each of these factors was projected into the future by identifying two up to four projections. The projections are "extreme" projections and describe possible but not very likely realizations of the factors to cover all possible developments. Since there are nearly twenty years of development to be considered the probability of each projection cannot be estimated. The projections are described in a way they are possible and based on current research but represent extreme developments concerning the key factor. Using a consistency matrix the projections were rated regarding the consistency of each pair. 317 pairs were rated, resulting in 13.824 possible combinations of bundled projections each including one projection for each key factor. The raw-scenarios are deduced choosing the most homogenous bundles while assuring the heterogeneity of the resulting scenarios themselves (see Figure 2). Due to the fact, that the final scenarios must be as selective as possible, finally three scenarios (see Figure 4) have been derived:

- The sustainably economical scenario focuses on an energy supply system like it is partly introduced by the German government [7] and the European SET-Plan [1]. The amount of wind and solar based electricity increased drastically. Manifold measures were taken by a wise political and market based environment, to cope with the resulting fluctuating and decentralized generation in terms of an economic operation. This led to an appropriate development of both the transmission and distribution grid. A system wide ICT infrastructure fosters load shifting which is primarily applied by industrial customers. A high degree of interoperability was reached by international standards, political guidelines and also industry standards. One the one hand this results in relatively high expenses for electricity compared to the overall household incomes and in a high volatility of the prices but on the other hand it enables a large variety of novel and innovative services. This combination, finally, leads to a high acceptance within the overall population.

- An inconsistent political framework led to an energy system which is trapped by complexity. The needed modifications within the transmission grid were not made but the distribution grid was developed to meet smart grid requirements. Only few wind power plants and photovoltaic were installed, whereas centralized renewable generation like solar power from Southern Europe or Northern Africa was successfully integrated and supported by further low-carbon and non-fluctuating generation. As a result, the volatility of the energy prices is not significantly increased and the level relatively high compared to today. Load shifting is extensively used by the industry and only by exception, e.g., electric mobility, by households. The availability and functionality of the ICT infrastructure differs regionally. Thus, beside the load shifting services only few services are provided within the system. In the overall system interoperability is reached in certain way by proprietary solution and partly considered market standards.
- The structure of the energy system is very similar as it is today. The transmission grid was developed to foster energy trade on a European level. Politics supported the change of the view on the strategy regarding the energy mix and decelerated or even stopped the installation of renewables. The result is an energy mix mainly consisting of fossil generation and nuclear power. Neither load shifting nor new services and products are part of the overall system. Only few basic services are available. Despite a missing unified ICT infrastructure, interoperability was achieved by politics and the market. Finally, the household's expenses for electricity are on a high level facing low volatility.

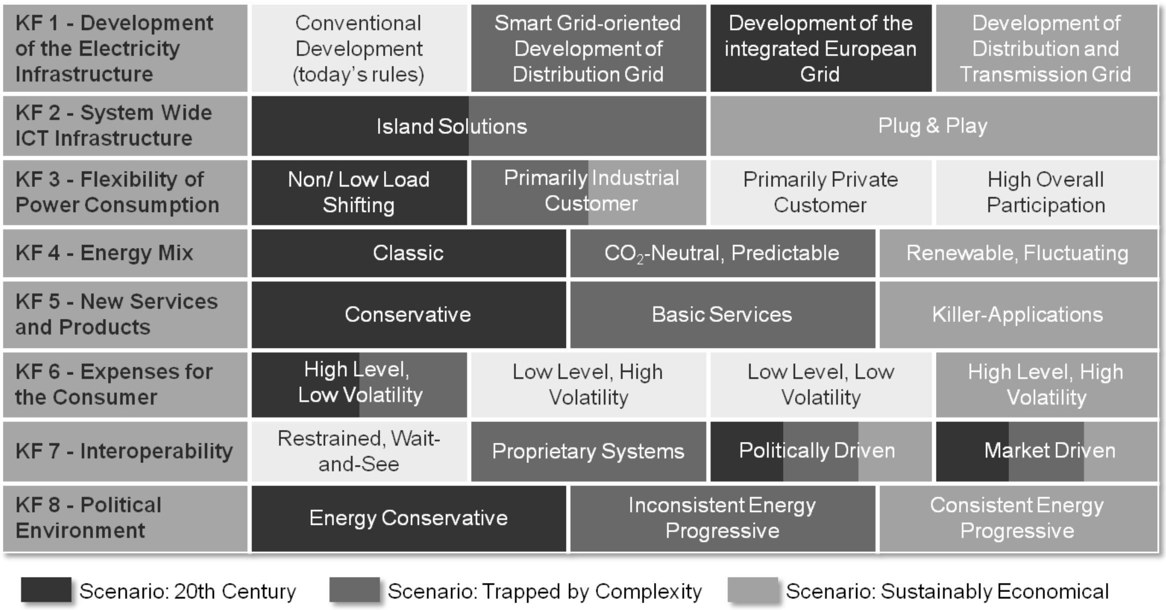

Figure 4: Scenarios Based on the Projections of the Key Factors

5. Results

Based on the scenarios for a Future Energy Grid system functions were identified. Those have been divided into different levels regarding the use of ICT. One level can be characterized as a closed system and is called the *Closed System Level*. Within this level access and control of system parts is strongly restricted because the components may affect the security of electricity supply which is determined as a critical infrastructure. On the other hand there is the *Networked System Level*. This level contains components that are located in the distribution grid and aim to play a significant role in the smart grid. These assets are characterized by a high amount of communication in order to provide advanced functionalities. The third level is the *ICT – Infrastructure Level* which includes components and communication standards to communicate within and between the different ICT Levels.

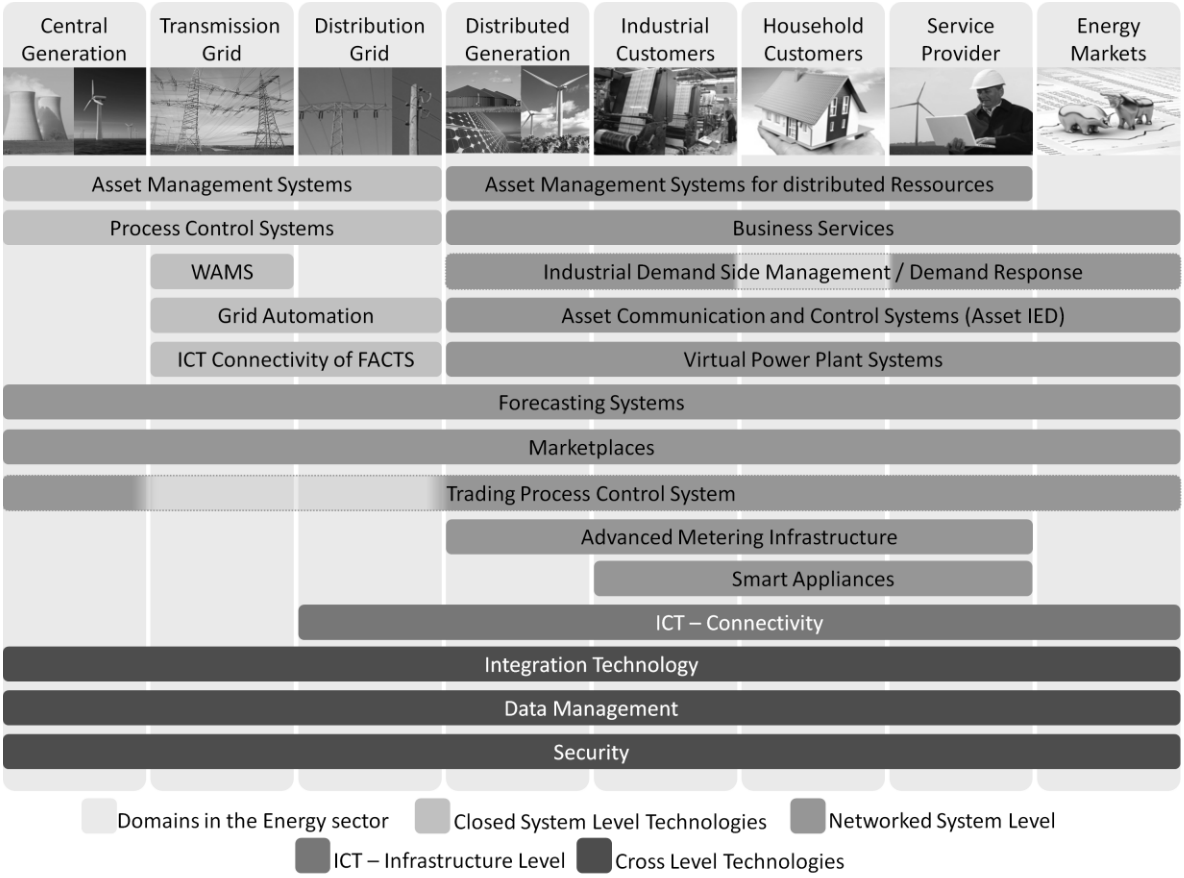

Figure 5: Technology Fields and Their Classification by Domains and System Levels

Figure 5 gives an overview on the identified technology fields and attributes them to the existing domains in the Energy sector and the system levels addressed above. The *Closed System Level* contains the following five fields: *Asset Management Systems, Process Control Systems, Wide Area Measurement Systems (WAMS), Grid Automation* and *ICT connectivity of Flexible AC transmission system (FACTS)*. The *Networked System Level* includes the ten technology fields *Asset Management Systems for distributed Resources, Business Services, Industrial Demand Side Management / Demand Response, Asset Communication and Control Systems (Asset IED), Virtual Power Plant Systems, Forecasting Systems, Marketplaces, Trading Process Control System, Advanced Metering Infrastructure* and *Smart Appliances*. The ICT-Infrastructure Level includes the technology field *ICT – Connectivity* which enables all authorized participants a non-discriminating access to needed information. Besides these three groups there are three technology fields that span across all domains as Cross Level Technologies. This group includes the fields *Integration Technology*, *Data Management* and *Security*.

Each of these nineteen technology fields have been analysed having regard to the domain, the actors, the branch, speed of development and maturity level. Within the analysis a brief description of the technology field is given with the main focus on future developments in the technology field. Based on these results the expected developments for each technology field can be identified and dependencies between the technology fields accentuated. Figure 6 illustrates dependencies between technology field steps and the approach to match these steps with the scenarios.

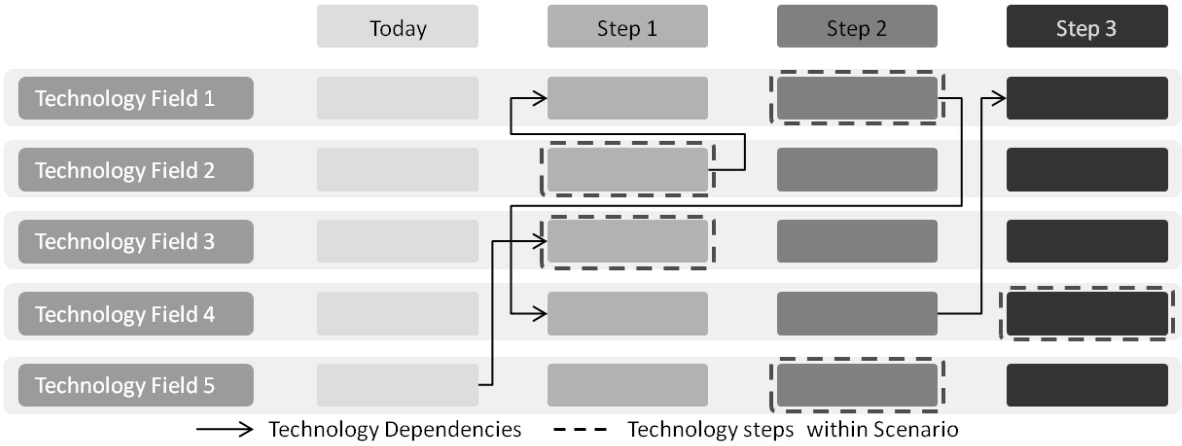

Figure 6: Schematic Technology Field Dependencies and Allocation to Scenarios

The classification of technologies and their dependencies enable the work on the migration paths. The continuing project work will determine which development steps within the technology fields are required for each of the three scenarios mentioned before. With the needed technology steps for each scenario a scenario migration path can be drawn. In addition to the targeted time period for the scenario the migration plan can then be used as an indicator for required incentives in technology research plans.

6. Business Benefits

The developments and results described within the sections above provide a reference for decision makers concerned with the energy system regarding investments and legislation. The results value derives from the global approach chosen in this work. The technological options (in respect to ICT) suitable for the evolution of the German power system and the gaps to be closed are depicted. Since society and the political system are essential regarding the implementation of new technologies, social acceptance and legal regulation are covered. This offers the possibility for politics, industry and society to innovate the system within a sensible legal framework with a result to be accepted by all participants.

Since sustainable energy supply is a global topic, other countries will be considered in respect to differences and similarities regarding environmental, economical and political aspects. This allows classifying the current activities of smart grid development with regions providing similar conditions and challenges ahead.

7. Conclusions

The paper addresses the challenges in developing an ICT based power system to meet the future requirements. While there is a lot of specific research on smart grid topics "Future Energy Grid" creates an integrated approach dealing with technological, political and social aspects. By this approach the research results fulfil two functions. On the one hand they sum up research done on smart grid topics. On the other hand new results are obtained. The development of smart grid scenarios and migration paths for ICT, create the context for further research while also giving concrete recommendations for actors in politics and economy.

The ongoing work in the project will determine what development steps are needed in the different scenarios resulting in a technological roadmap. As this contribution focuses on the methodology used to develop the scenarios for the German electricity grid by 2030, derived from identified key factors as well as on the development of certain technology fields and their developments, the future work will concentrate on more environmental influences. Hence, one main concern is research on the acceptance of ICT in smart grids. Another focus will be on the assessment of Germany compared to other countries playing key roles in smart grid developments. Finally, regulation will be covered by a detailed analysis of the current situation. While the obtained results are specific to Germany the methodology used may be applied to other countries in order to develop scenarios and technological migration paths.

Acknowledgements

The project "Future Energy Grid" is funded by the German Federal Ministry of Economics and Technology (BMWi) as part of the E-Energy-Framework (grant number 01 ME 10012A). It is coordinated by OFFIS and by acatech. Further project partners are BTC/EWE, Nokia Siemens Networks, RWE AG, SAP AG and Siemens AG. We want to thank everyone contributing to the results presented in this paper.

References

[1] European Commission, *A Technology Roadmap for the Communication on Investing in the Development of Low Carbon Technologies (SET-Plan)*, 2009.

[2] U.S. Department of Energy, *Communications Requirements of Smart Grid Technologies*, Department of Energy, 2010.

[3] State Grid China, *SGCC Framework and Roadmap for Strong & Smart Grid Standards*, State Grid - Corporation of China, 2010.

[4] ENTSO-E and EDSO, *The European Electricity Grid Initiative (EEGI)*, European Network of Transmission System Operators for Electricity (ENTSO-E), 2010.

[5] H.-J. Appelrath, C. Mayer, and S. Rohjans, "Auf dem Weg ins Internet der Energie - Future Energy Grid," *Energy Talks Ossiach 2011*, Ossiach, 2011.

[6] J. Gausemeier, C. Plass, and C. Wenzelmann, *Zukunftsorientierte Unternehmensgestaltung - Strategien, Geschäftsprozesse und IT-Systeme für die Produktion von morgen*, Carl Hanser Verlag, München, 2009.

[7] Bundesministerium für Wirtschaft und Technologie (BMWi), *Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung*, Bundesministerium für Wirtschaft und Technologie (BMWi), 2010.

[8] European Commission, *Energy efficiency: delivering the 20% target*, European Commission, 2008.