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COST-BENEFIT ANALYSIS OF SMART GRIDS PROJECTS IMPLEMENTATION

SUMMARY

Smart Grids are one of a key component of the EU strategy towards a low-carbon energy future and efficient energy use. From an economic point of view, it's main characteristic is big investment, and benefits are seen after some time with risk of being smaller than expected. Therefore it is important to make a comprehensive cost-benefit analysis of those projects.

Paper presents restrictions of current electric power networks along with solutions that are offered by Smart Grids. Guidelines for conducting the cost-benefit analysis of Smart Grid projects are compared and applied on pilot projects, to demonstrate use of methodologies for reducing uncertainties and incentivizing investments. As a part of qualitative analysis, social aspect of Smart Grid projects is described.

In the end of this paper, it is given an overview of what has been done and what will be done in European Union.

Key words: Smart Grids, cost-benefit analysis, electric power system, social aspect.

1 INTRODUCTION

From economic point of view, main goal of Smart Grids is implementation of new technologies and systems, exploiting current capacities, with minimal funds possible, to enable efficient usage of electric energy on all levels, from production to consumption. Primary characteristic of such grids are big initial costs and benefits manifest after some time with certain risk rate of savings being lower than costs. Problem is that such characteristic makes Smart Grids risky to invest into. So before implementation of the grid it is necessary to do cost-benefit analysis which will inform investors about profitability of their investments, as well as qualitative analysis which will show investors comprehensive picture of influence of the project to stakeholders, environment and society in general. Until now, many studies have tried to identify the benefits of the Smart Grid, but far fewer have focused on developing a systematic way of defining and estimating them. EPRI (Electric Power Research Institute, USA) developed first and so far the best methodology for economic analysis of Smart Grids with benefits and expenses for entire society, including qualitative impact analysis. Hypothesis is that systematic methodology would help in reducing uncertainties and incentivizing investments. The goal of this paper is to make a fair allocation of short-term costs, additional costs in projects of integrating electricity from variable renewable energy sources into the electric power system, long-term benefits among different players and social aspect of Smart Grid projects comparing existing methodologies and pilot projects.

2 DEFINITIONS, ADVANTAGES AND IMPORTANCE OF SMART GRIDS

In European Union Smart Grids are defined as grids that intelligently connect behavior and operation of all users connected to it (Figure 1.) in attempt to optimize the efficient, reliable, safe and secure delivery of electricity [1, 2]. Smart Grids are meant to improve global protection of environment and lower harmful effects on climate, such as emissions of CO_2, efficient use of electric energy of consumers, increase rate of renewable and distributed sources of energy in production, and finally strengthening of the electric energy market. It is expected that such Smart Grids would also contribute climate and energy policies in European Union until 2020, 2030 and 2050 [3]. Smart Grids are defined similarly in USA, but unlike European Union, main goal of USA politics is to introduce new jobs and increase economical worth and efficiency of electric power network.

Electric power network of today is facing problems caused by increased demand for electric energy, new technologies and system integrated into existing network (renewable energy sources, electric vehicles, energy storage), need to lower harmful emissions, fear of terrorist attacks on centralized units of energy production, and demand of consumers related to reliability and quality of electric supply. Smart Grids solve these problems and offer efficiency and reliability of supply and high quality energy services for all participants in electric power network.

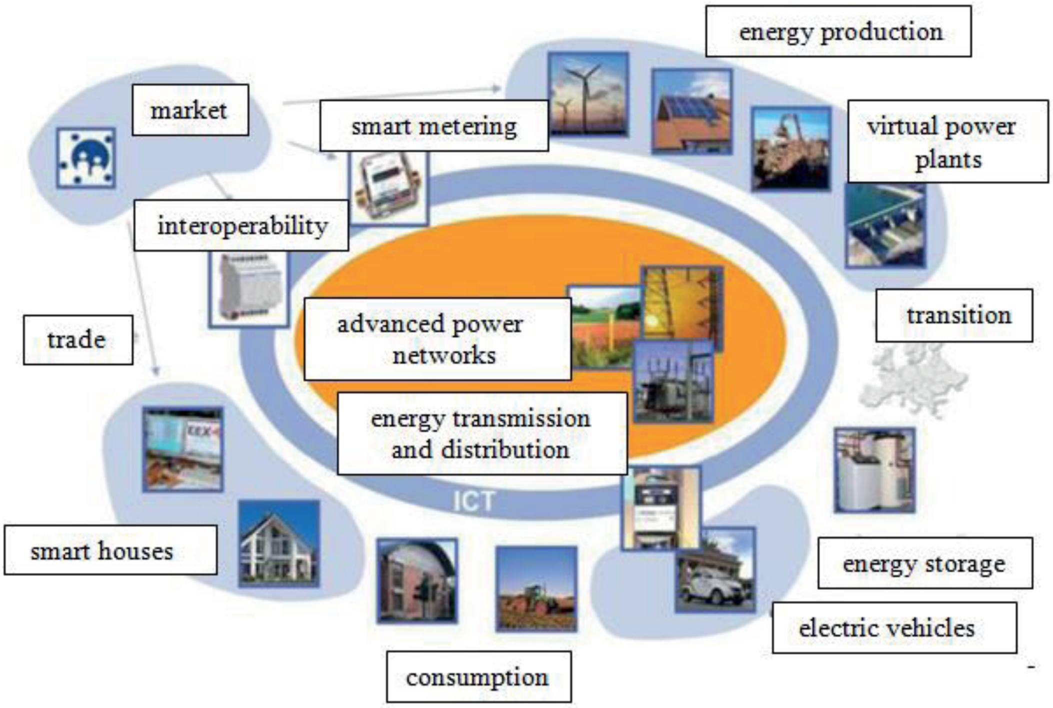

Figure 1. Parts of Smart Grids [2]

Fundamental difference between existing grids and Smart Grid, together with main advantages of Smart Grid, are summarized in Table 1.

Table 1. Comparison of key features of presented grids and Smart Grids [5]

	Current Grid	*Smart Grid*
Communications	None or one-way; typically not real-time	Two-way, real time
Customer interaction	Limited	Extensive
Metering	Electromechanical	Digital (enabling real-time pricing and net metering)
Operation and maintenance	Manual equipment checks	Remote monitoring, predictive, time-based maintenance
Generation	Centralized	Centralized and distributed
Power flow control	Limited	Comprehensive, automated
Reliability	Prone to failures and cascading outages; essentially reactive	Automated, pro-active protection; prevents outages before they start
Restoration following disturbance	Manual	Self-healing
System topology	Radial; generally one-way power flow	Network; multiple power flow pathways

3 COMPARISON OF METHODOLOGIES FOR COST–BENEFIT ANALYSIS OF SMART GRID IMPLEMENTATION PROJECTS

This article consist in brief, a fair allocation of short-term costs, additional costs in projects of integrating electricity from variable renewable energy sources into the power system, long-term benefits among different players and social aspect of Smart Grid projects comparing existing methodologies. There are steps in cost benefit analysis according to three most common methodologies.

3.1 EPRI methodology

EPRI methodology for economic analysis of costs and benefits of Smart Grid projects consists of ten steps (Table 2.) grouped into 3 categories: project description, definition of benefits and costs and comparison of defined costs and benefits.

Table 2. Ten-Step Approach for Cost-benefit analysis according to EPRI methodology [6]

	TEN-STEP APPROACH FOR COST-BENEFIT ANALYSIS
Characterize the project	1. Project's technologies/elements and goals
	2. Smart Grid functions provided by project
	3. Project's Smart Grid principal characteristics
	4. Mapping functions to benefits
	5. Establishing project baselines
Estimate benefits	6. Identify and obtain the data needed to estimate the baseline and to calculate each type of benefit
	7. Calculate quantitative estimates of the benefits
	8. Estimate the monetary value of the benefits
Compare costs to benefits	9. Estimating the relevant costs
	10. Comparing costs to benefits

Review on the project's technologies/elements and goals. The first step is to summarize representation and description of technologies, elements and goals of the project. It involves defining grid size (annually power consumption, number of grid users), local characteristics of the grid, identification of participants of the grid that bear the costs and benefit from the grid, socio-economic impact of the grid and finally regulations of grid implementation. It is possible to define technologies from one of these categories:

- Advanced metering infrastructure
- Advanced technologies in distribution system
- Integration of advanced systems (renewable energy sources, electric vehicles)
- Consumption control system and smart houses
- Energy storage

Smart Grid functions provided by project. Second step is grouping components according to their function. There are 33 different functions possible separated into six groups [6]:

- Enabling the network to integrate users with new requirements
- Enhancing efficiency in day-to-day grid operation
- Ensuring network security, system control and quality of supply
- Better planning of future network investment
- Improving market functioning and customer service
- Enabling and encouraging stronger and more direct involvement of customers in their energy usage and management

Project's Smart Grid principal characteristics. Third step is defining main characteristics with which the project contributes to accomplishment of Smart Grid goals, which are:

- Possibility of involvement of consumers into consumption control
- Possibility of integration production facilities and power storage
- Improvement of the energy market
- Ensuring quality of electric energy
- Efficient control of grid elements
- Prevention, detection and removal of malfunctions
- Protection against damages and malfunctions

Mapping functions to benefits. Fourth step is grouping functions/functionality that grid components preform according to benefits they cause. There are four main benefit types, three perspectives and four levels of precisions of estimated benefits and costs listed in Figure 2.

Four main categories of benefits are:

- Economic – reduced costs, or increased production at the same cost
- Reliability and power quality – reduction in interruptions and power quality events
- Environmental – reduced impacts of climate change and effects on human health and ecosystems due to pollution
- Security and safety – improved energy security (reduced oil dependence); increased cyber security; and reductions in injuries, loss of life and property damage

Table 3. Four categories of uncertainty levels [7]

LEVEL OF PRECISION	*PROBABILITY THAT THE ACTUAL VALUE IS WITHIN CERTAIN RANGE*	*RANGE WITHIN THE ACTUAL VALUE IS*
MODEST	80%	±20%
SIGNIFICANT	80%	±40%
HIGH	95%	±100%
UNCERTAINTY RANGE	cannot be quantified	

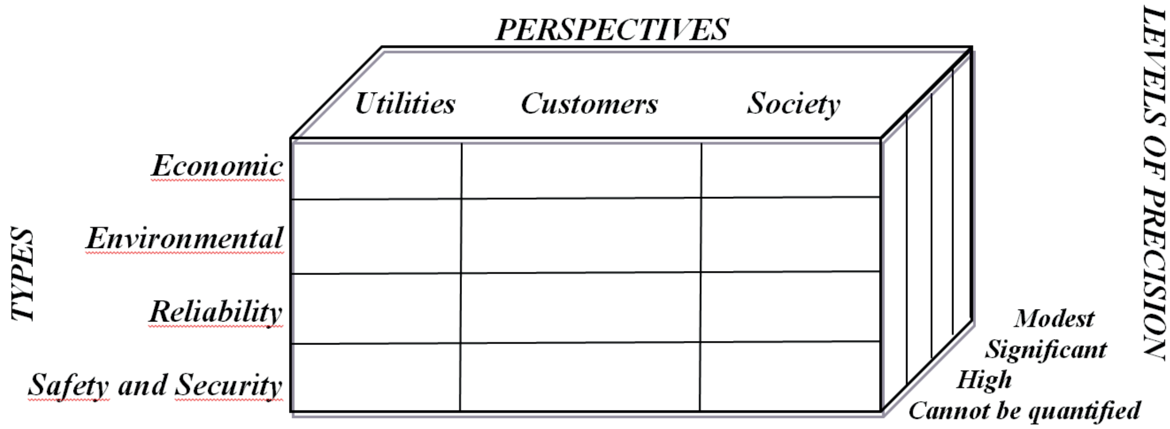

Figure 2. Types, perspectives and levels of precisions of estimated benefits and costs [7]

Establishing project baseline. Fifth step is establishment of referential (basic) state which all other states will be compared with. Referential state can be determined based on historical (for relatively stable conditions) or forecasted data (for conditions that are expected to vary over short time periods) about consumption. When testing new products or services referential data are reactions of consumer groups on such products or services. It is important to ensure that consumer group is random and represents all grid users realistically.

Benefits calculation. Sixth, seventh and eighth steps regard to quantification of benefits and identification of grid participants which are benefiting. Monetary worth of realized benefit is calculated as difference between referential state and state in Smart Grid.

Estimating the relevant costs. Ninth step is especially important in order to calculate time in which invested money will return. Essentially those are investments and operational expenses. During the integration of intermittent energy sources, because of their specific characteristics such as variability, unpredictability, modularity, small marginal cost, additional expenses are unavoidable:

- Balancing expenses - expenses of ensuring reserve capacities to satisfy demands
- Grid-related impacts and costs - expenses of reinforcement, expansion and connection to the network
- System adequacy impacts and costs - expenses to ensure reliability of supply considering reliability of production of intermittent power plants in time of peak load (Capacity credit), and decreasing usage of conventional power plants, and thus lowering their profitability (Utilization effect)

Table 4 provides a summary overview of total integration costs – including the three constituent components – for three technologies (wind offshore, wind onshore and solar) at the penetration levels (10% and 30%) in three selected EU countries (France, Germany and the UK), as estimated by NEA (2012). In general, the major component of total integration cost is accounted for by grid-related costs (ranging from about 45-65% of total costs), followed by adequacy costs (20-35%) and balancing costs (15-20%).

Table 4. Estimates of variable renewable energy integration costs in selected EU countries (in €/MWh) [8]

		Wind onshore		*Wind offshore*		*Solar*	
FRANCE	**Penetration rate**	**10%**	**30%**	**10%**	**30%**	**10%**	**30%**
	Grid connection	4.9	4.9	13.0	13.0	11.2	11.2
	Grid reinforcement and extension	2.5	2.5	1.5	1.5	4.0	4.0
	Total grid-related costs	7.3	7.3	14.6	14.6	15.2	15.2
	Adequacy (back-up) costs	5.7	6.1	5.7	6.1	13.6	13.9
	Balancing costs	1.3	3.5	1.3	3.5	1.3	3.5
	Total system integration costs	**14.3**	**16.9**	**21.6**	**24.1**	**30.1**	**32.6**
GERMANY	*Grid connection*	4.5	4.5	11.0	11.0	6.6	6.6
	Grid reinforcement and extension	1.2	15.6	0.6	8.3	2.6	33.2
	Total grid-related costs	5.7	20.0	11.6	19.3	9.2	39.8
	Adequacy (back-up) costs	5.6	6.2	5.6	6.2	13.5	13.8
	Balancing costs	2.3	4.5	2.3	4.5	2.3	4.5
	Total system integration costs	**13.6**	**30.7**	**19.5**	**30.0**	**25.0**	**58.1**
UK	*Grid connection*	2.8	2.8	13.9	13.9	10.9	10.9
	Grid reinforcement and extension	2.1	3.6	1.8	3.2	6.0	10.6
	Total grid-related costs	4.8	6.4	15.7	17.0	16.9	21.5
	Adequacy (back-up) costs	2.8	4.8	2.8	4.8	18.3	18.8
	Balancing costs	5.3	9.9	5.3	9.9	5.3	9.9
	Total system integration costs	**13.0**	**21.2**	**23.8**	**31.8**	**40.5**	**50.2**

Comparing costs to benefits. Tenth step in economic analysis is comparison of costs and benefits in order to determine profitability of the project. It is possible to conduct annual comparison, cumulative comparison or ratio of invested and obtained. Method of Net present value NPV is calculated as a difference between sums of discounted worth of savings (difference between benefits and costs over n years with the discount rate r) and investment costs I_0. Investment is profitable if NPV is positive (1).

$$NPV = \sum_{t=0}^{n} \frac{(benefits - \cos ts)_t}{(1+r)^t} - I_0 \quad (1)$$

Internal rate of profitability, IRR is discount rate with which NPV is zero, and investment is profitable if IRR is larger of equal than set discount rate [8].

3.2 JRC methodology

JRC[1] method of economic analysis of Smart Grids is composed of seven steps [6]. In comparison with EPRI methodology, third step in which main characteristics of Smart Grids are estimated is skipped. In second and fourth step terms of function and functionality are switched, because functions refer to technical benefits only and functionality on technical, environmental and societal. Another modification is grouping of the sixth, seventh and eighth steps because they all refer to definition of benefits. In addition to stated, for analysis of grids in Europe, it is suggested to define input parameters for analysis and conduction of parameter sensitivity analysis which define range of input parameters for which project is still profitable.

3.3 Analysis of implementation of smart metering projects

Implementation of smart meters is one of the oldest and most used technologies during construction of the Smart Grid, so it is often separately analysed. The analysis is conducted in five main steps [10].

First four steps contain economic analysis of implementation of smart meter projects. Description of the projects includes rate of implemented smart meter, time period of the analysis, and functionalities which are taken into account. Scenarios which observed projects are compared with are "Business as usual" (without implemented smart meters) and scenario predicted in year 2020 (advanced counters implemented in 80% of consumers, with minimal functionalities).

Some of the parameters that have to be defined before analysis of the project are assessment of energy consumption deviation, assessment of energy price deviation, reduction of peak load, estimated duration of supply termination, VOLL, discount rate, unit costs of equipment, amount of implemented advanced counters, price of installation, expected lifetime of the smart meter, expenses of consumption reading, share of communication technology, plan of implementation, implementation in urban or rural areas, taxes for CO_2 emissions...

As well as for any of the other implemented smart system, economic analysis of expenses and benefits is conducted through already stated seven steps. Specificity which differentiates analysis of smart meters implementation projects lies in functions, benefits and expenses.

Analysis of sensitivity, as with JRC methodology results in rage of variables for which the project is still profitable.

With higher quality analyses of project one must take into account effect on external factors such as increase in number of jobs, increased reliability of supply, positive impact on environment, protection of privacy and increased comfort of consumers.

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[1] The Joint Research Centre (JRC) is the European Commission in-house science service. It provides independent scientific and technical advice to the European Commission to support a wide range of European Union policies [9].

4 APPLIANCE OF METHODOLOGY ON SMART GRID PILOT PROJECTS

In the Netherlands KEMA and CE Delft (2012) made a report based on the social cost-benefit analysis of Smart Grids. [11] This analysis corresponds to economic analysis of above mentioned methodologies. There are allocated costs and benefits, including social aspect through external effects. Costs and benefits are compared using Net present value method.

They run three scenarios,

(i) the business as usual (BAU 2050) with only a limited CO_2 emissions reduction,
(ii) combination (C&N 2050) of Coal with carbon capture and storage & Nuclear (80-95% CO_2 reduction) and
(iii) combination (R&G 2050) of renewables and gas (80-95% CO_2 reduction), represented in Table 5.

The benefits far outweigh the costs in every scenario. This means that Smart Grids are profitable, even under the scenario of little to no intermittent renewable energy sources on the market. The C&N scenario comes out as the most profitable choice as many of the energy sources as many of the electricity generation plants are already in place and the electricity produced is non-intermittent meaning there is less need for additional generation and grid investments.

Table 5. Cost-benefit of Smart Grid deployment in Denmark, in the three scenarios [11]

NPV (€ billion)	*BAU 2050*	*C&N 2050*	*R&G 2050*
COSTS			
Investments in Smart Grids	-2,10	-2,10	-2,10
Operation & maintenance Smart Grids	-2,50	-2,50	-2,50
Costs need to be determinate	Costs for new equipment, Welfare loss due to changes in timing in response to pricing		
Total costs	-4,60	-4,60	-4,60
BENEFITS			
Avoided grid investments	2,50	5,80	4,10
Avoided electricity losses	0,30	0,50	0,90
Avoided investments in centralised generating capacity	1,20	5,10	1,00
Avoided investments in large scale electricity storage	0,00	0,00	0,10
More efficient use of electricity	1,30	1,40	1,60
Energy savings	0,70	0,70	1,50

NPV (€ billion)	*BAU 2050*	*C&N 2050*	*R&G 2050*
COSTS			
Lower load issues	0,40	0,50	3,20
External effects	0,60	0,10	0,10
Benefits need to be determinate	Welfare loss due to comfort and time gain		
Total benefits	7,10	14,10	12,50
BALANCE	2,50	9,50	7,90
Internal interest rate	13%	28%	31%

5 SOCIAL EFFECT OF CONDUCTION OF SMART GRID IMPLEMENTATION

Social effect refers to inclusion of consumers into functioning of Smart Grid, as well as effect of Smart Grid on consumers, community and society in general. Degree of Smart Grid development is greatly dependent on inclusion of consumers into control of their own consumption, and main motivations are care about environment, lower bill for electrical energy, and finally feeling of comfort and satisfaction. Thus operators of electric power networks are trying to encourage consumers to be more included by introducing fixed and variable charges, rewards or competitions (e.g. Green offices).

Reasons for sceptical attitudes of consumers towards implementation of Smart Grids are large investments, risk of not achieving sufficient savings, concern about their health or privacy, fear of remote control over their access to energy and similar. However, Smart Grids have numerous advantages for consumers (comfort, lower receipts for used power, reliable supply, high quality energy, control over their own consumption), community (reliable supply, mutual exchange of energy at favourable prices), and society in general (care about environment, reliable supply) [12].

6 SMARTGRIDS IMPLEMENTATION PROJECTS IN EUROPEAN UNION SO FAR AND FUTURE PLANS

JRC (Joint Research Centre) in the newest catalogue [13] published analysis of projects of Smart Grid implementation in countries of European Union by June 2013. 459 projects of Smart Grid implementation were conducted, where 47 countries participated and total investment was 3.15 billion euros. According to IEA, for renewable power system from production to distribution Europe should in period from 2007 to 2030 invest 1.5 billion euros [1].

6.1 Systems of smart metering of electrical energy consumption in European Union

According to Directive 2009/72/EC, the goal of energetic grid of EU members is to supply at least 80% of consumers with smart meters by 2020. So far the plan of implementation was conducted in Finland, Sweden and Italy, which make 23% of desired 80%. 16 members of EU have decided that Smart Grid implementation would be profitable investment, and started preparations for their integration into electric grid. 4 members of EU so far did not evaluate integration of Smart Grids profitable investment so far (Lithuania, Czech Republic, Belgium, Portugal), and 4 countries have not conducted the analysis so far (Slovenia, Hungary, Bulgaria, Cyprus). Germany, Latvia and Slovakia are conduction integration in some consumer groups only. It is estimated that by year 2020 72% of consumers have implemented smart meters, which involves 200 million consumers and requires investment of 35 billion euros [13]. As a part of EU, Croatia wants to implement smart meters into 80% of households until 2018. too.

7 CONCLUSION

Advanced technologies so far were developed in technical way, but were not harmonized with other systems on the grid, so optimal function of Smart Grid was not achieved so far. Hypothesis given at the beginning of this paper that systematic methodology would help in reducing uncertainties and incentivizing investments is confirmed with an example of Smart Grid implementation in Netherland. It is important to analyse conducted projects, publish reports and exchange knowledge and experiences so benefits to social goals would be more easily monitored, energy market opened, investors encouraged, consumer trust established and strategical plan of Smart Grid construction developed.

8 ABBRIVATIONS

IEA – International Energy Agency

EPRI - Electric Power Research Institute

NEA – Nuclear Energy Agency

NPV – Net Present Value

IRR - Internal Rate of Return

JRC - Joint Research Centre

VOLL – Value of Lost Load

KEMA - Keuring van Elektrotechnische Materialen te Arnhem

BAU - Business as Usual

C&N - Coal with Carbon Capture and Storage & Nuclear

R&G - Renewables and Gas

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