Czech Technical University in Prague

Faculty of Electrical Engineering

Doctoral Thesis

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SYSTEMATIC APPROACH FOR IMPLEMENTATION OF SMART TECHNOLOGIES INTO THE ENERGY INDUSTRY

Doctoral Thesis

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II. Content

III. Abbreviations

AF	Asset Financing – This term is used for obtaining loans or borrowed capital using balance sheet assets (such as accounts, receivable, short-term and other investments).
AMI	Advanced Metering Infrastructure – System composed of AMM and smart appliances utilizing management of consumption beyond the customer.
AMM	Advanced Metering Management (represents measuring subset of AMI) – Measurement devices using two way communication.
BAU	Business As Usual – This term is used for scenario of future development, where global emissions of CO_2 are regulated only by market forces without any regulation.
CAPEX	Capital Expanses
CBA	Cost Benefit Analysis
CCCma	Canadian Centre for Climate Modelling and Analysis
CCS	Carbon Capture and Storage
CGEI	Centralized Global Energy Industry
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CO_{2eq}	Carbon Dioxide Equivalent – It express amount of CO_2 which has the same influence (mostly on greenhouse effect) as particular amount of other gas.
CPI	Consumer Price Index
DAS	Decentralized Ancillary Service
DCHP	Decentralized Combined Heat and Power
DEC	Data Energy Coupling
DPI	Decentralized (Distributed) Power Industry
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
EAT	Earnings after Tax
EB	Energy Branch
EBIT	Earnings Before Interest and Tax
EI	Energy Industry
EIS	Energy Industry System = System of whole energy branch
EU	Europe Union
EV	Electric Vehicle
EVA	Economic Value Added

FRM	Flow Reliability Margin
GB	Great Britain
GDP	Gross Domestic Product
GHG	Greenhouse Gasses
HTS	High Temperature Superconductors
IPCC	Intergovernmental Panel on Climate Change
IPO	Initial Public Offering – This term is used for a very first offer of particular share on the market.
ITC	Investment Tax Credits – It reduces a state income from commercial activity based on e.g. RES-E operation.
LEP	Local Electricity Price
LBM	Local Balancing Market
LC	Local Congestion
LCC	Local Congestion Capacity
LR	Technology Learning Rate
LRMC	Long-Run Marginal Costs
LS	Load Shifting
LTPA	Local Third Party Access
M&A	Mergers and Acquisitions
MESC	multiple energy sources concurrence
MSG	Multi Smart Grids
MVA	Market Value Added
NFFO	Non-Fossil Fuel Obligation
NOPAT	Net Operating Profit after Taxes
NPP	Nuclear Power Plant
NPV	Net Present Value
OTC	Over the Counter – This term represents the off-exchange trading.
PIPE	Private Investment in Public Equity – This tem represents investors´ purchase of stock at a discount for the purpose of raising capital.
PE	Private Equity – This term represents investment into companies that have no shares on stock markets but but the investors by this investment obtains the share on the company’s equity therefore it is not similar to common bank loan.
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PM	Public Market
PPP	Purchasing Power Parity
PR	Progress Ratio

PV	Photovoltaic-
R&D	Research and Development
RD&D	Research, Development and Deployment
RDD&D	Research, Development, Demonstration and Deployment
RES-E	Renewable Energy Source
ROC	Renewables Obligation Certificate
ROIC	return on invested capital
RPS	Renewable Portfolio Standard – This term represents quota for electricity produced in RES-E.
RPSM	Reactive Power Smart Management
SA	Substantial Aspect of author's analysis
SAIFI	System Average Interruption Frequency Index[1]
SAIDI	System Average Interruption Duration Index[2]
SG	Smart Grid – There are lots of available definitions. Author´s definition is as follows: Smart Grid is concept of management of modern electricity grid, utilising AMI.
SLP	Smart Local Price
SRMC	Short-Run Marginal Costs
S/RP	Small/Residential Project
SP	Smart Price
ST	Smart Technology
STS	Smart Trading System
SWF	Social Welfare
TPA	Third Party Access
TSO	Transmission System Operator
USA	United States of America
USD	US Dollar
VC	Venture capital – In the US this term is used for PE investment to very young (and mostly risky) companies.
VHTR	Very High Temperature Reactor
WACC	Weighted Average Cost of Capital

[1] It represents one of basic electricity retail reliability criterion - average system frequency of electricity retail interruption.

[2] It represents one of basic electricity retail reliability criterion - average systematic time of electricity retail interruption.

IV. Nomenclature

AC	[monetary unit]	allowed cost
AE	[monetary unit]	allowed earnings
AR	[monetary unit]	allowed revenues
B	[monetary unit]	generally benefit
B_{acc}	[monetary unit]	benefit of accumulation utilization
$B_{\mathrm{concurrence}}$	[monetary unit]	benefit from various energy commodities shifting
B_{ill}	[monetary unit]	benefit of illegal consumption avoidance
$B_{\mathrm{integration}}$	[monetary unit]	benefit of various consumption monitoring coupled under SG
$B_{\mathrm{inv.\ D/TSO}}$	[monetary unit]	benefit from transmission and distribution system investment avoidance
B_{MOB}	[monetary unit]	benefit from electromobility utilization
B_{market}	[monetary unit]	benefit from price changes intraday (by smart tariffs)
B_{monitor}	[monetary unit]	benefit from cross border monitoring
B_{REG}	[monetary unit]	benefit of decreased costs for grid regulation services
$B_{\mathrm{RES\text{-}E}}$	[monetary unit]	benefit of electricity price increase upon SG
EB	[monetary unit]	the economic benefit
EBm	[monetary unit]	the economic benefit guaranteed by market conditions for the operator of ST
EBr	[monetary unit]	is the economic benefit of the implementation guaranteed by particular regulation for the operator of ST
Γ	[monetary unit]	capital (employed in some investment)
C	[W/Wh]	electricity consumption
C_0	[W/Wh]	consumption before particular change
C_{AMI}	[monetary unit]	discounted AMI communication costs
C_{C}	[liter, year]	consumption of classical vehicle
C_{Debt}	[monetary unit]	capital costs connected with external financing
C_{E}	[Wh]	yearly consumption of electricity (of the hybrid Vehicle)
CF	[monetary unit]	cash flow
C_{G0}	[Wh]	original stable consumption in the local grid
C_{H}	[liter]	consumption of hybrid vehicle
C_{M}	[monetary unit]	total discounted marketing and market penetration costs

$C_{manageable}$	[W]	capacity of manageable consumption
$C_{non\text{-}manageable}$	[W]	capacity of non-manageable consumption
coef	[1]	applicable coefficient of simultaneousness
C_{OP}	[unitary monetary unit]	operating costs of AMI
Cost	[monetary unit]	generally cost
$Cost_{inv.D/TSO}$	[monetary unit]	costs into transmission and distribution system without SG concept
$Cost_{inv.D/TSO\_SG}$	[monetary unit]	costs into transmission and distribution system with SG concept
$Cost_0$	[unitary monetary unit]	cost of the first produced unit during technological learning process
$Cost_{acc}$	[unitary monetary unit]	cost per unit during technological learning process
C_{REG}	[monetary unit]	costs of regulation services without SG
C_{REG_SG}	[monetary unit]	costs of regulation services with SG
d	[%]	discount
D_t	[monetary unit]	residue of external capital
$D\&A_t$	[monetary unit]	depreciation and amortization
EBIT	[monetary unit]	earnings before interest and tax
EVA	[monetary unit]	economic value added
η_e	[W/J]	efficiency of electricity production with simultaneous heat production
η_{th}	[J/J]	efficiency of heat production without simultaneous electricity production
η_{th_e}	[J/J]	efficiency of heat production with simultaneous electricity production
$FCFE_t$	[monetary unit]	free cash flow to equity (shareholders)
G_G	[W]	available generation capacity in global grid
$G_{manageable}$	[W]	capacity of manageable generation
$G_{non\text{-}manageable}$	[W]	capacity of non-manageable generation
i_i	[%]	inter-bank interest (mostly EURIBOR)
I	[monetary unit]	investment (cost)
I_{AMI}	[monetary unit]	AMI investment costs
I_C	[monetary unit]	investment into classical vehicle
I_E	[monetary unit]	investment into necessary equipment for plug-in charging
I_i	[monetary unit]	operating CAPEX cost (state-of –the –art cost)
I_H	[monetary unit]	investment into hybrid vehicle

$\vec{In}(t)$	[vector]	inputs to the system
$Interest_t$	[monetary unit]	interest to be paid to the lender
k,n	[1]	universal variables for quantity
$k_{t\ a}$	[1]	manageable parameter of simultaneousness between appliances
$k_{t\ h}$	[1]	manageable parameter of simultaneousness between households
L	[W]	capacity for losses coverage in the grid or capacity of some consumers as applicable
l_A	[W]	load of appliances from group A
l_B	[W]	load of appliances from group B
LCC	[W]	local congestion capacity
l_D	[W]	load of appliances from group D
l_{E1}	[W]	load of parked PHEV/PEV charging
l_{E2}	[W]	load of house accumulator
L_m	[W]	maximal average household load
L_{Tm}	[W]	total load of group of consumer (e.g., village)
m	[1]	general variable for number of pieces
MVA	[monetary unit]	market value added
n	[1]	general variable for number of pieces
$nonCFC_t$	[monetary unit]	non-cash cost
$NOPAT$	[monetary unit]	net operating profit after taxes
NPV	[monetary unit]	net present value
NPV_{CUS}	[monetary unit]	net present value for customers
$\vec{Ou}(t)$	[vector]	outputs from system
Π	[1]	experience parameter
P	[monetary unit/W]	price of electricity
$P_A – P_E$	[monetary unit/W]	represents electricity prices for appliances from groups A – E
p_E	[monetary unit/(W, year)]	yearly average price of electricity
p_e	[monetary unit/(W)]	generally the price of electricity
$p_{e\_peak\ h}$	[monetary unit/W]	electricity price during peak hours (“high smart price”)
$p_{e\_offpeak\ h}$	[monetary unit/W]	electricity price during off-peak hours (“low smart price”)
Pe_{RES-E}	[monetary unit/(W, year)]	price of particular RES-E electricity without SG concept is implemented

$Pe_{\text{RES-E\_SG}}$	[monetary unit/(W, year)]	price of particular RES-E electricity with SG concept is implemented
p_F	[monetary unit/liter]	price of fuel
P_G	[monetary unit/W]	is price in global grid
p_{gas}	[monetary unit/J]	is price of natural gas
P_L	[monetary unit/W]	local price of electricity
PR	[%]	progress ratio, rate at which unitary cost declines of every doubling of production
$P_{TGC\ 0}$	[monetary unit/---]	predicted price of TGC
$P_{TGC\ S}$	[monetary unit/---]	real price of TGC
P_{trans}	[1]	transformation of inputs in the system
Pw_e	[W]	electrical power consumption
Pws	[W]	power shifted by the means of demand response
Pw_{th}	[J]	thermal power consumption
Q	[W]	quantity of consumption that ensures grid stability
$Q_{crossborder}$	[W]	volume of electricity transported without SG concept
$Q_{crossborder\_SG}$	[W]	volume of electricity transported with SG concept
$Q_{TGC\ 0}$	[1]	predicted volume of TGC
$Q_{TGC\ 0S}$	[1]	volume of TGC according to real supply curve for predicted price
$Q_{TGC\ S}$	[1]	real volume of TGC
$Quality$	[1]	quality of electricity retail reliability
r	[%]	discount rate
rm	[%]	risk margin which contains risk bonus and margin for the lender
ΔR_{TGC}	[monetary unit]	difference of TGC revenues
$ROIC$	[%]	return on invested capital
$\vec{S}t(t)$	[vector]	state variables characterizing system
SV_e	[W]	electricity consumption savings
svr_e	[%]	electricity consumption savings ratio
svr	[%]	electricity transport savings ratio
SV_c	[monetary unit]	capital savings
SWF	[1]	social welfare
t	[year]	time
T	[year]	lifetime
T_0	[year]	date of start of commercial operation of SG concept

T_D	[year]	year to which discounting is performed
T_P	[year]	beginning of pre-operation investment period
τ	[%]	tax rate
V	[W, pcs]	capacity or number of implemented devices
$\vec{V}_A$	[1]	Vector of availability
V_{acc}	[produced units]	cumulative unit production
$WACC$	[%]	weighted average cost of capital
$\vec{V}_P$	[1]	Vector of electricity price

operand ´ (quotation mark) marks variable limited in closed grid

*operand * (star) marks time variable in real grid which can be managed by local AMM / AMI devices in the SG concept*

Applicability of physical units W (power) / Wh (energy) depends on interpretation. When considering particular time unit the power [W] is applicable. Regarding integral analysis the energy [Wh] will be applicable.

V. Images

VI. Tables

1 Introduction

The whole Energy Branch (EB) (Energy Industry – EI) is now in the crucial point. The socio economic aspects begin to impact on this industry massively. The customers are now connected to energy industry as direct market participants and electricity market undergoes more or less successful changes in the way of higher liberalization, represented mostly by legislation changes in the whole European Union (EU). The lots of such aspects and changes inter alia result in brand-new energy smart technologies (ST) development. This dissertation thesis represents a short introduction into the way how to valuate and describe these smart technologies implementation using systematic approach to this end. One of these ST is smart grid. Smart grid (SG) is a term that has recently become widely discussed along especially with the boom of renewable resources (RES-E) and with a brand new approach to the energy branch, i.e. with mitigation of CO_2 emissions and fight against global climate change, as it is discussed e.g. in [1]. Most of the RES-Es work on principles that do not enable the control of their generation. These are called intermittent resources. This fact impacts massively the transmission of electricity grid capacity reserves. It is publicly known that the massive development of intermittent (non-manageable) resources, along with the long-term increasing of energy demand, puts higher and higher requirements on the transmission system‘s capacity. This problem will be more visible e.g., with future plug-in electric vehicles (PEV) or local micro RES-E expansion. Task for today’s engineers is therefore to solve the future sustainability of the energy branch together with ST expansion. Smart grid (SG) concept provides according to the authors opinion one possible way but it will not support the social welfare (SWF) increment without appropriate application of suitable implementation methodology. This thesis therefore describes SG concept regarding decentralized power industry, together with nodal prices occurrence.

The energy branch is in whole thesis, explained as a very complex system. For influence of outputs of such system is necessary to find the optimal value of inputs and also establish a correct system of relations between particular subjects. The only optimal principles of economic motivation are principles resulting in the win-win strategies. Realization of such strategy is quite difficult but not impossible. This strategy therefore remains a big challenge for today’s energy economists and it is the only way how to keep a consistent SWF increment.

1.1 Goals of the Thesis

The framework of ST sector of power industry represents large and diverse branch. Research and description of such a big branch would represent challenge for large amount of researchers and it would require massive support. Therefore the author of this thesis chose one part of ST sector, smart grid.

Public articles concerning with SG are mostly descriptive and marketing aimed, explaining the promises of manufacturers of advanced metering infrastructure (AMI). There are very little scientific articles describing SG from the systematic viewpoint. Author´s thesis therefore represents first-of-its-kind analysis of real SG implementation impacts. Author´s goals for his thesis are as follows:

1.1.1 Description of Main Aspects of Energy Branch

As a basis for research the author has conducted description of today´s energy branch with its main aspects. The environment for author´s research is the entire energy branch in this thesis. Smart grid in this point of view constitutes one representative of smart technology applicable into the energy branch. This description process is necessary for formulation of author´s systematic analysis. SG is analysed as a subsystem of energy branch (chapter 3.4.1).

1.1.2 Description of Today´s Theoretic Framework for ST Concept Implementation

For the deep analysis of SG implementation the author conducted description of state of the art of smart technologies implemented into the energy branch as well as the financing methods applicable for research and development (R&D) and ST implementation. This description is provided by the author in chapter 3.4 and chapter 3.5. This introduction constitutes for the author part of theoretical basis for his research.

1.1.3 Formulation of Systematic Description of Energy Branch

The Author´s analysis is based on the application of systematic approach. Energy branch represents system with its infrastructure of market participants and internal connections between them. In addition to that any structural change would provoke a feedback. Smart grid represents subsystem of the energy branch. Therefore this description represents other important part of theoretical basis for author´s research.

1.1.4 Formulation of Methodology for Smart Grid Impacts Valuation

Formulation of cost benefit analysis of SG implementation is one of the important results of author´s analysis. This result originates in application of analysis based on the systematic approach. Without such a cost benefit analysis some implementation impacts can be ignored which would not comply with the author´s systematic viewpoint.

1.1.5 Identification of Real Impacts of SG Implementation

Author has identified lots of consequences originating in SG implementation. These consequences are highly applicable for future development of business for commercial market participants. Therefore these are presented in this thesis.

1.2 Author´s Hypothesis

Author´s hypothesis is that implementation of smart grids concept would influence energy branch as a system; all market participants and relationships between them as well.

Impacts of SG concept implementation can be more or less predicted by using systematic analysis. Smart grid is used in author´s analysis as a case study for application of systematic approach. Systematic approach is used for identification of aspects of smart grid future development as well as for formulation of cost benefit analysis (CBA). Moreover the author has to identify important aspects connected with the future SG implementation. For better understanding, the sub hypotheses supporting the author´s hypothesis were formulated.

1.2.1 Sub hypothesis 1

Totally independent behaviour of distribution system operator and trader represents problem for applicability of demand response in the SG concept.

1.2.2 Sub hypothesis 2

SG concept would enable brand new construction of electricity price, different from the one known today.

1.2.3 Sub hypothesis 3

SG concept would prepare environment for the new status of electricity customer.

1.3 Motivation

In scientific manuscripts no authors have chosen really analytical approach for SG implementation assessment. SG Concept emerged in Italy with totally different conditions in energy branch. Italy with a large amount of intermittent renewable resources or gas power plants and with no nuclear power plants (NPP) has problem with the grid stability. SG is said to be promising in lots of marketing announcements and articles. Such articles mostly originate in manufacturers of advanced metering infrastructure (AMI). Only little scientific manuscripts represent real objective and scientific analysis. They are formulating real characteristic of implementation of SG but they have not use systematic analysis approach to this end. Therefore the European Union prepared legislation [2] that should encourage member states for SG implementation under condition of economical meaningfulness.

Analysis conducted by the systematic approach provides results applicable for the future development because it is based on feedbacks. Feedback is mediated by impacts of implementation. This feedback is mostly postponed for a few years because of large inertia of the system (power industry). Lots of author´s results can be therefore apparent after process of implementation and today it can help market participants with preparation and seeking new opportunities[3]. Therefore results of this thesis are new and lots of them should be discussed in the future after experience with SG implementation is done. Author´s results suitable for discussion in future scientific works are summarized in chapter (chapter 8.1).

1.4 Structure of the Thesis

The structure of this thesis can be described as follows. In chapter 1 the goals and thesis for this dissertation thesis are formulated. The author utilizes his research methods described in chapter 2.

The ST are parts of modern Research and Development (*R&D*) projects segment. The following part of the thesis (chapter 3) answers the question why the discussion about ST began. Chapter 3.5 describes main principles of investment suitable for ST implementation.

Chapter 4 represents theoretical approach to the theory of system which is according to author of this thesis suitable for ST impacts implementation valuation. Author therefore uses this methodology as a fundamental basis for all analyses and theories presented as goals of this thesis. Next part (chapter 5) contains basic ideas and principles of economic motivation which is necessary for formulation of correct ST implementation methodology. Without right motivation these new technologies would not be able to bring the frequently mentioned social welfare (SWF) [1], [3].

The described and by the author formulated theoretical approach is applied on the case of smart grid (SG) implementation in chapter 6, which is mostly known as a most perspective ST that is said to bring massive savings of energy as well as capital [4], [5], [6],. The conclusion of this thesis contains the proposed methodology that should be suitable for ST implementation (previously published [7]) connected with the discussion about the aspects of its impacts.

[3] For example large RES-E support results in need of transmission grid investment or massive market price decrease, that would result in necessity of new motivation for investors into not supported generating capacities. If the systematic approach had been used in the past, these facts could have been predicted a priori.

2 Methods of Research

The energy branch (EB) can be generally seen as a system transforming of inputs originating in its environment. The outputs represent results of transformation process in the system. The transformation process is moreover influencing the inputs by the feedback [8], [9]. This fact represents first resolution approach and is visible in Fig 1. In more detailed resolution each system consists of its sub-systems, creating its structure. These sub-systems have its inputs and outputs as well. Method of author´s research is systematic analysis of EB. Smart technologies (ST) and in more detailed view smart grids (SG) are classified as a subsystem of the whole EB. Author utilizes the analysis to investigate the structure of the sub-system as well as the relationships between elements creating it (applied in chapters 5 and 6). The mentioned sub-systems, presented in EB are investigated using method of analogy between existing sub-systems and future sub-system, mostly smart grids.

The systematic analysis provides relevant description of today´s energy branch. In the way of more detailed description needed for case studies (chapters 6.6, 6.7 and 6.8) author of this thesis applied deduction process. For synthesis of theoretical aspects revealed during systematic analysis the smart grid concept was chosen as a most promising smart technology influencing moreover the whole EB infrastructure. From the above described analysis of the system author deducts impacts of SG sub-system implementation for the market as well as for all market participants.

2.1 State of the art

During his research the author studied literature connected with SG. The findings were quite surprising because there are mostly marketing publications dealing with the economy of SG concept. Only exceptionally some manuscripts and books (e.g. [1]) try to discuss the economic aspects of SG but without systematic approach. Such a literature moreover does not formulate any methodology for implementation impacts valuation. Really scientific manuscripts deal mostly with technical problems of smart grid infrastructure, its security and electricity measurement and data transport. Conferences about SG mainly represent opportunities for AMM - manufacturing companies´ presentations. Besides, there is no real long-time experience with SG operation. Therefore it was very difficult for the author to find relevant data applicable for his research. The additional support and resources for author´s analysis was provided by discussions with experts from energy branch and publications presented on conferences, that author attends, e.g. [10].

This thesis can be therefore called unique and it has not comparison with some other publicly known scientific manuscripts dealing with similar aim. Framework of this thesis is very broad and has overlaps to more parts of energy branch.

2.2 Theoretical Basis

Theoretical basis for author´s research is deep analysis of energy branch infrastructure (i.e. market participants and relationships between them). SG implementation will influence position of consumer and his relationship with market participants. Measuring of electricity flow in connection points and its high speed processing is not involved in today´s grids. Therefore relevant real time data is missing. Therefore data of consumption and in some distributed resources generation is processed ex post. Payments of customers to electricity utilities are in the same time based on deposit payments.

Theoretical basis for author´s research is not only technical features of described system of energy branch but also economical. The author moreover presumes that the motivation of system elements (market participants) is influenced by feedback originating in the system. Synthesis of technical and economic aspects of system development guides the author to reach the goals of this thesis.

2.3 The General System Approach

The infrastructure of subjects involved into energy branch can be seen as a structure of a system. The development and outputs of any system are characterized by their inputs and by feedback. In the first resolution, the trivial schema of a general system is on Fig 1.

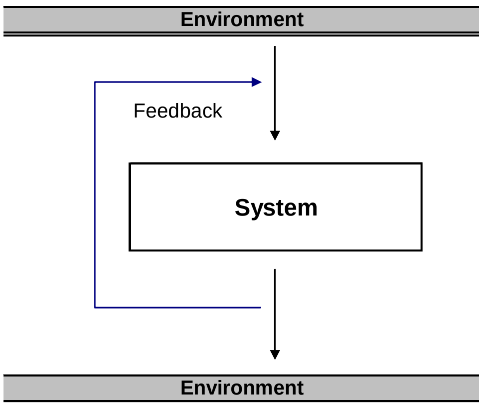

Fig 1. *System in the first resolution*

More detailed resolution will divide one box named "System" from Fig 1 to more partial systems and subsystems (chapter 4.2). According to this philosophy, SG is subsystem of the whole Power Industry and power industry is an environment for SG. In other words the system of power industry represents environment for subordinated subsystems, e.g. advanced metering infrastructure (AMI) which represents hardware infrastructure for smart grid concept.

Inputs can be transformed in each part of the system (in each sub-system) differently. They came from environment and can be caused by artificial as well as natural influences. In the second resolution the outputs from some sub-system can be inputs to another sub-system. The structure of upper-system constitutes environment for subordinated sub-systems and in the same time transformation of upper-inputs is influenced by structure of sub-systems as well.

Every system transforms inputs into outputs. The process of transformation can be described by equation (1).

$$\vec{O}u(t) = P_{trans}\left[\vec{I}n(t), \vec{S}t(t), \vec{F}b(t)\right], \quad (1)$$

where $\vec{O}u(t)$ represents vector of outputs/responses of the system, $\vec{I}n(t)$ represents vector of inputs, $\vec{S}t(t)$ represents vector of State variables, $\vec{F}b(t)$ is feedback and operator P_{trans} represents transformation process. All variables are time dependent.

Vector of state variables characterizes the system and represents borders for the process of transformation as well as internal infrastructure of subjects in the system. Transformation of inputs is represented by operator P_{trans} which is set by internal relations in the system. Future development of the transformation process is regulated by feedback. The Feedback determines sustainability of the system.

3 Smart Technologies in the Energy Branch

For author´s research conducted by the means of systematic approach, is necessary to characterise the theoretical basis of research [11]. To this end the author summarized main aspects of energy branch as well basic principles of modern technologies implementation. According to systematic approach (chapter 2.3) the whole energy branch is subsystem of global (or national) economics. From the viewpoint of ST or SG the energy branch represents environment that provides inputs for subsystems ST / SG. For the author´s research, it is necessary to analyse not only infrastructure of market participants but also related legislation, support schemes and ways of ST projects financing.

The energy branch stands today in front of many challenges. These challenges originate mostly from the environment, security, business and social area. They are connected with the concept of sustainable development because the energy sector influences sustainable development of the global civilization more than majority of another business segments.

The best known today's challenge is avoiding the global climate change caused by emissions of greenhouse gasses. According to some scientific studies, the global temperature could grow for 1 – 3 °C in this century [12]. The most popular arrangement against the global climate change is massive reduction of greenhouse gases emissions. Such reduction in value of thousands of Mt CO_{2eq} will need very close cooperation of developed and developing countries as well as massive changes in the structure of energy branch.

3.1 Description of Today's Energy Branch

The Energy industry was only partly liberalized. The endeavour of unbundling principle [13] is to establish liberalized market optimization into the electricity market; however this market represents only a part of the power industry. The electricity market structure can be therefore divided into two parts today. The first part is Liberalized segment and second is regulated segment as it is shown on Fig 2.

Regulated are mostly the grid sectors (transmission and distribution) and generation of electricity in RES-E. Such sectors are either not competitive with classical technologies or investment spend for establishment of concurrent environment would be too high. It is of course not economical to build another concurrent grid to establish some competition in the sector of grids operators. Therefore some regulation (made by state authority) in this sector can be deemed as reasonable.[4] Another part of this regulative agenda is also support of "natural

[4] The only way how to establish concurrence in electricity delivery is the use of natural gas (which uses different distribution channels) in Combined Heat and Power (CHP) devices (discussed in

friendly" technologies e.g. renewables (RES-E) that are not able to compete with classical technologies today. The theoretical basis for this support is discussed in [14].

The possibility of access to the grid (for both generators and consumers) should be free which is said to contribute to energy market competition establishment.[5] The same situation is with electricity trading because electricity as a commodity takes place on free markets (exchanges or OTC). Liberalization is opportunity for competition. On the other hand according to [15] the liberalization could result in avoiding of capital-intensive technologies with long construction and life times. This phenomenon became more visible in despite of their obviously low marginal costs. Because of risk avoidance the short time horizons are preferred.

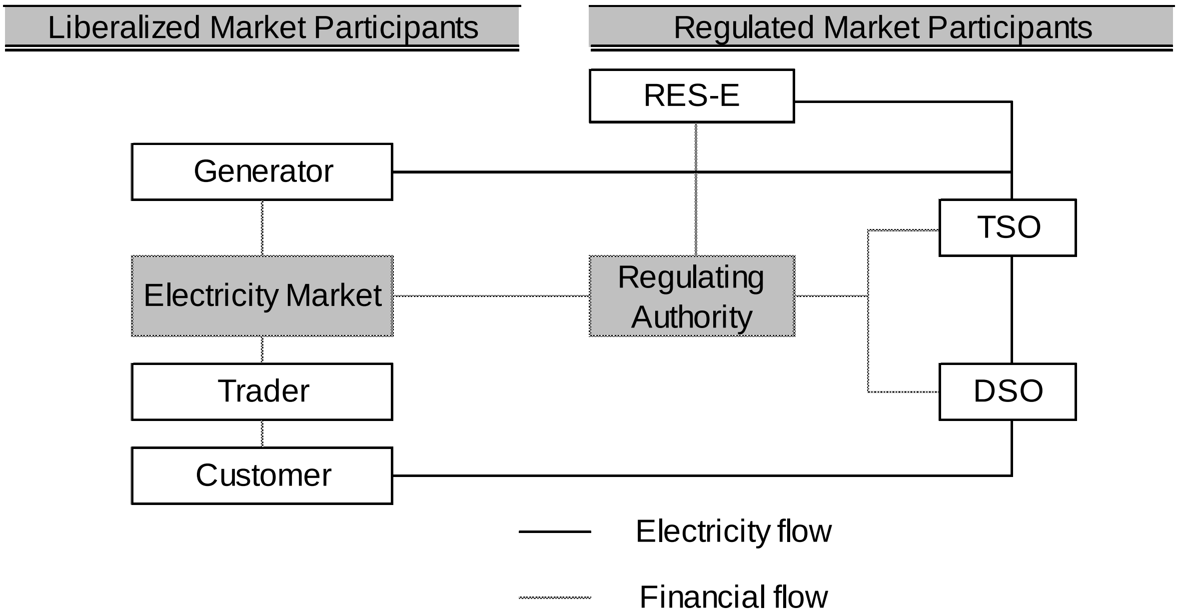

Fig 2. *Electricity market structure*

This system was established by the legislation in the western countries to mitigate the naturally monopolistic structure of energy branch and to establish the possibility of free market optimization on the electricity market. For the EU countries this described liberalization was enforced by [13].

3.1.1 Liberalized Segment

This segment allows market participant to free market conduct and by the means of free market optimization to buy and sell electrical energy as a commodity on market more information e.g. in [16]. For end customers with low consumption

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chapter 6.4.4 as $B_{concurrence}$) or by usage of batteries. Such devices could on condition of SG implementation displace necessity of electricity transport.

[5] This is according to effort of the EU (manifested e.g. in [13]) one of important steps to reach free market and liberal capital allocation in the power industry.

(mostly households and little companies) the trader buys electricity on market and customers can shift between particular traders. The particular participants are:

- **Generator:** not supported by particular feed-in tariff or by another way described in chapter 3.8).
- **Trader:** can serve as retailer to final customer as well as speculator - arbitrager on the market.
- **Customer:** household or company without special department for electricity trading.

3.1.2 Regulated Segment

Regulated segment in contrary represents part of market where no free conduct of participants is possible. Basically because of real physical obstacles it is not possible to shift between transmission or distribution system operators (TSO, DSO). Their province is set by particular geographical area. The particular participants therefore are:

- **Transmission System Operator (TSO):** responsible for long distance and high voltage electricity transmission.
- **Distribution System Operator (DSO):** responsible for short distance and low voltage electricity transmission.

Another part of regulated segment is represented by participants that obtain some support according to particular legislation. In the EU this legislation is based on [17]. Vast majority of such supported participants is recruited from RES-E. The particular participants therefore are:

- **RES-E:** renewable resources produce mostly uncompetitive electricity which is supported in the way of future CAPEX descent according to prevailing expertise opinion, described e.g. in [18].
- **Decentralized Micro Generators:** generators supplies directly to low and extra low voltage grids produce more valuable electricity because of multiple transformation mitigation.
- **Combined Heat and Power (CHP):** usage of heat in the places where electricity is generated in thermal plants enlarges the total efficiency of thermal cycle of such plant. In more detail the total exergy (fraction of energy available to be used during thermal cycle) is larger than without utilization of thermal power. Contrary anergy (fraction of energy unavailable for effective utilization) is lower.

3.2 Electricity Price Structure

The mentioned facts have massive impact on customer electricity price structure. Situation in the energy branch differs from lots of other industries; therefore final electricity price for customers consists from two parts. One part is set by competition of electricity as a commodity on liberalized market; the second part as a majority of the price is set by regulation performed by state authority because of costs originating in regulated sectors [19].

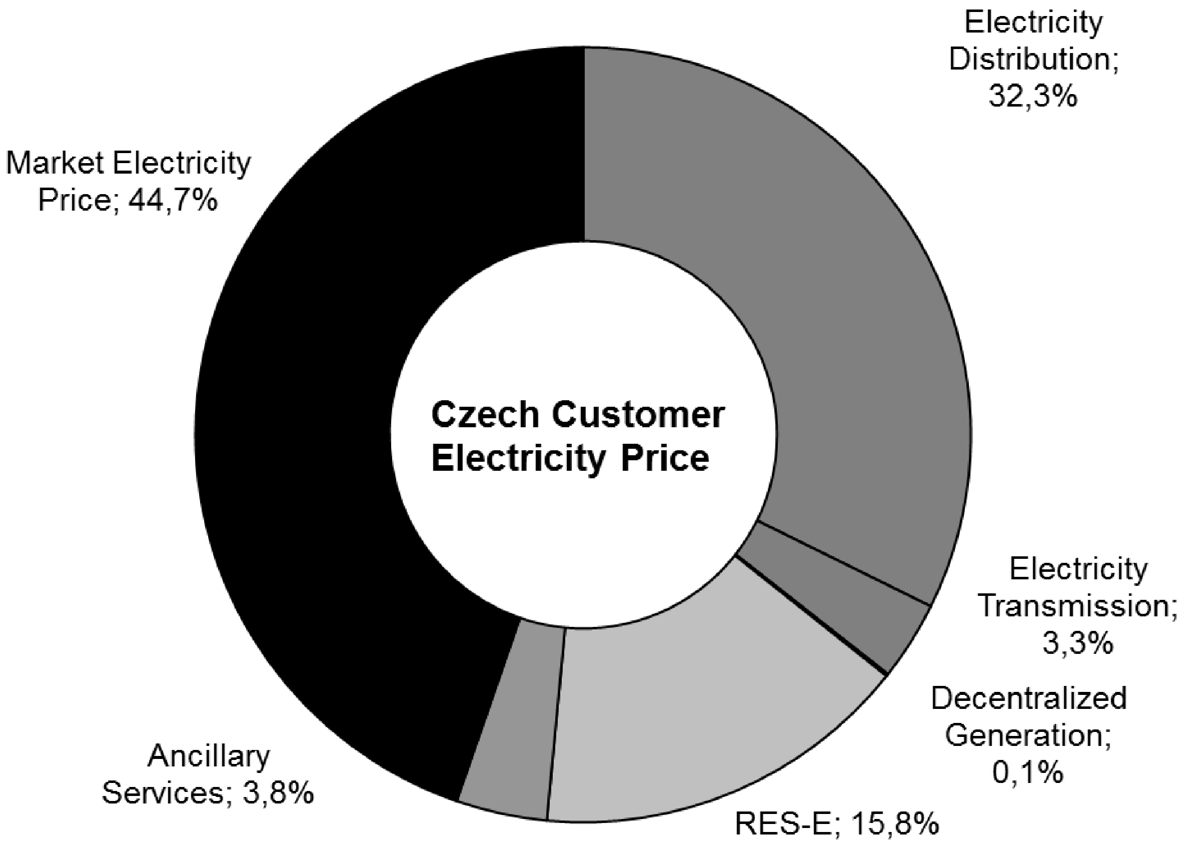

Fig 3. *The real structure of price on Czech retail market according to Czech Energy Regulatory Office (2013) [19].*

It is important to underline that these regulation consist of taxes, fees and duties that collect the capital form electricity customers. This capital is afterwards distributed between those market participants that are acceptors of particular subventions.

The main attributes of particular fractions of electricity price are in Table 1. The dependence on local conditions represents very important aspect of particular price fractions. The division presented in Table 1 have to be changed after massive ST and especially SG deployment.

Table 1. Detailed structure of price on Czech retail market [20], [19].

Part of the Price	Origin	Depends on	Local grid dependence	Paid by	Status
Market power price	Trader	Market price development	NO	Consumed electricity (MWh)	Liberalized
	Regulatory authority	Expenditures of invoicing	NO	partly paid as fix fee by each customer	Regulated
Ancillary Services	Regulatory authority	Expenditures spent by TSO for ancillary services procurement	NO	Consumed electricity (MWh)	Regulated
RES-E + CHP	Regulatory authority	RES-E and CHP share on total power generation	NO	Consumed electricity (MWh)	Regulated
Electricity operator	Regulatory authority	Expenditures of market operator operation	NO	Consumed electricity (MWh)	Regulated
Electricity transmission*	Regulatory authority	Expenditures of TSO operation to guarantee maximal consumption	NO	Reserved capacity (maximal consumption) (A)	Regulated
Electricity distribution	Regulatory authority	Expenditures of DSO operation to guarantee maximal consumption	YES	Reserved capacity (maximal consumption) (A)	Regulated
Decentralized generation	Regulatory authority	Decentralized generation support	NO	Consumed electricity (MWh)	Regulated

* For decentralized low-voltage customers it is contained in Electricity distribution price [20].

3.3 Reasons for the ST Implementation

The modern system of economy used in western countries based on the free market was considered to be very effective, mostly in the way of market competition and the price making. The market based economy turned out to be effective in the past, mostly for the capital distribution between particular market participants. According to some authors [15] and in more general meaning [21] strictly free market capital distribution do not need to be optimal in some branch of economy in long run. Nowadays these doubts should be taken into account during formulation of strategy for any structural changes in the energy branch. Free market optimization and competition of strictly liberalized market participants can, regarding to [15] have problem with providing of investment incentives in following parts of energy branch.

- **Future strategic resources availability:** Reservoirs of fossil fuels are not limitless. Today's civilization is constricted by the fear from post-fossil age with high electricity prices. The supported RES-E can solve or shift this problem to the future but but today's price for this is high (chapter 3.8).
- **Future environmental conditions:** The future consequences of today's economic activity cannot be today taken into account in strictly market governance, i.e. without any regulation. There exist some predictions for the future development but but there is no consensus about it.
- **Sustainable development:** Today's economic crisis discovers the unsustainability of free market driven economy without appropriate regulation.

The power industry can be therefore seen as a system. To establish stability of the system development a negative feedback is according to my opinion needed as it is written in chapter 4. The mentioned regulation, as it is written below, must be established effectively which is one of my conclusions. This feedback could prevent us from non-reversible changes in the power sector and transferred in whole environment.

The following list includes the most urgent problems that should be solved in the way of sustainable development in present-day power industry:

- The possible future lack of primary energy sources (mostly fossil ones).
- Sustaining of energy supply reliability at least on today's western standards.
- Mitigation of some unfavourable future climate change (reduction of the CO_2 can be possible way).
- Complex enhancement of the number of non-polluting ways of the electricity production.
- Drawdown of the local import dependence on the primary energy sources from politically unstable areas and countries.
- The future electricity demand satisfaction on condition of the global society lifestyle escalation. It can be represented by global SWF growth according chapter 4.2.5.3.

- More effective control of the transmission and distribution grid from the view of the losses lowering.
- Facilitation of the sustainable development.
- Minimization or sustaining of the all investment costs in the energy industry.

It must be mentioned here, that for popularization of R&D sector contributes very massive medial and political campaign of global warming. The most important phenomenon mentioned in this campaign as a result of the global climate change is global temperature growth.

The global climate change is phenomenon of complex change in global climate caused by growing temperature during the 20th century. Almost every local extreme weather event is according to this theory caused by this global climate change. Important is, that according to prevailing opinion the reason for the temperature growth, are emissions of CO_2. Objective pieces of evidence says, that during last century the

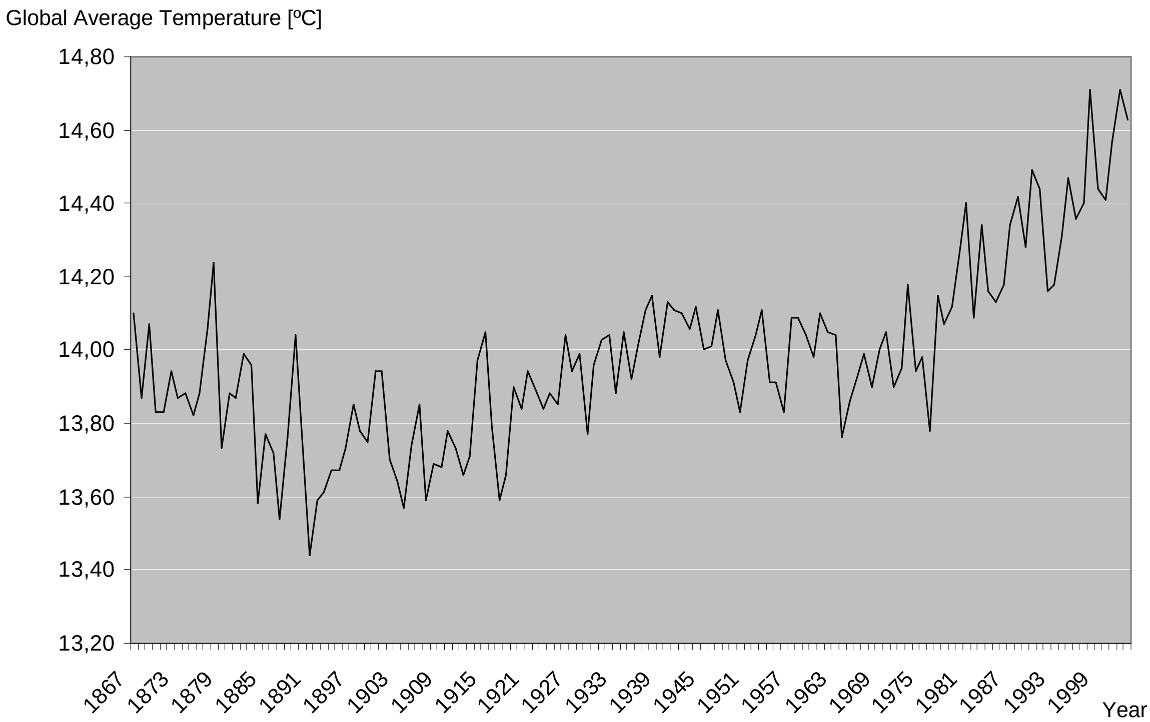

Fig 4. *Global temperature development since 19th century to present [22]*

Is global growth of temperature really caused by emissions of CO_2? The 20th century is time, when global climate was leaving a time period from 15th to 19th century, which is called “little ice age” and was characterized by very cruel winters and fall of temperature. This “opposite climate change” was without any doubts caused by anomaly in the solar cycle called maunder minimum, which was characterized by low solar activity. Therefore today's global warming could be comeback to weather conditions of time period around year 1000 A.D. In additional according to [22] the civilization produces not only greenhouse gasses but but also gasses that contribute to cooling of global climate, e.g. sulphur emissions.

ST and investment into R&D technologies should not be seen only as an instrument for CO_2 emissions elimination. This argument is used very often in media but real situation is as we can see in the chapter 3.3 not so trivial. The implementation of ST should bring in the future primarily savings of costs, mitigation of investment in unneeded enlargement of energy transport capacities (transmission and distribution grid) and also savings of feedstock. It should bring us cleaner environment and higher life standard. Not only CO_2 emissions reduction as it is presented in media.

3.4 The Smart Technologies in the Electric Power Sector

The new ST try to restructure the whole energy branch in the modern, effective and environmental friendly way but every new technology uses different way for reaching this “optimal status”.

Lots of these new technologies could on the other hand represent a “blind alley” because their implementation would be too much expensive and inconvenient for some group of subjects in the market. It could be surprising but according to author's opinion a technical constraints does not represent invincible problem. Therefore an economical part of this problem seems to be more important than the technological one! According to this idea the economical motivation must be solved to provide a realistic market conditions for the implementation.

Nowadays lots of smart technologies are known. Some are only ideas, some are prototypes and some have been already commercially used. According to experiences [4] from the segments of electricity market, the usability of particular technologies differs. The list in chapter 3.4.1 should provide a short and not exhaustive summary of the most important smart technologies with its advantages, disadvantages and effects. Additional information is presented in Supplement A.

3.4.1 Smart Grids

There are lots of definitions of Smart Grids available in the literature. The definition depends on viewpoint. Author of this thesis therefore uses his definition defining this term regarding his hypotheses. *The Smart Grid is concept of management of modern electricity grid, utilising advanced metering infrastructure (AMI) consisting of modern (smart) appliances and advanced metering management devices (AMM)*. The AMM enables two-way communication and consumption of smart appliances is manageable according to signals transmitted by AMM. These signals shall represent way of Smart Grid management. In author´s presented systematic approach the grid management by the means of SG concept represents feedback that enables grid to be effectively managed in the way of minimal consumer electricity price as well as physical requirements of the grid. Especially with growing number of RES-E represent unreliable element in the grid.

The smart grid should enable connection of smart devices and help with regulation of the grid. SG could be distinguished into two parts. The first are micro grids (local distribution grids) and the second are macro grids (transmission grids). After implementation of the SG it would not be necessary to increase a capacity of the current electric lines even if the consumption would grow. The successful implementation is dependent on motivation of the consumer and on the spread between the lowest (baseload) and the highest (peakload) price of electricity that can be utilized by demand side management (DSM), demand response (DR) and load shifting (LS).

- **Advanced metering (AMM)**: It is the way of metering which would be necessary complement of SG implementation. This metering should simplify the grid regulation, the breakdowns identification and quick reparation. It should also enable the two way communication between the consumer and the trading/distribution company. Its implementation will require high investment costs from consumer or distributor. On the other hand its implementation would enable large potential of savings as it is discussed in chapters 6 and 8.1. It enables in the same time two-way communication between customer and other market participants via classic telecommunication channels or via wires (high or low voltage).
- **Plug-in hybrid electric vehicles (PHEV)** / **Plug-in electric vehicles (PEV):** This concept is based on presumption that during low price of electricity (mostly during night when consumption is used to be lower or during times of large RES-E production) these vehicles are charged from the grid. During the day the car is commonly used. It has classical combustion engine and electro engine. The electro engine uses energy from accumulators. The accumulators are charged not only from the grid but also from braking using recuperation (only in case of PHEV). Massive implementation of these vehicles would require SG concept implementation (chapter 6.2.1). Moreover the plugged-in PHEV can serve as active accumulation in the grid. The PHEV would be in the future substitute for the classic cars. Therefore its future success on the market will depend on the development of the oil price as a complement to present day cars.
- **The new principles of electricity accumulation**: Effective accumulation of electricity would solve problems with instant

electricity price oscillation; with unpredictability of the RES-E production; it would help e.g. with black-outs. The efficiency stays however the most important problem. Also high price, low reliability and short lifetime stay serious problem.

- **Decentralized CHP**: Decentralized Combined Heat and Power will increase the efficiency of primary energy source usage. It couples the heat and electricity production on decentralized power stations. Its advantage is very high thermal efficiency.
- **Micro RES-E**: Installations of low capacity renewables placed mostly to places of consumption (by the customers).
- **Data energy coupling**: Represents brand new possible concept suggested by the author of this thesis that could be utilized for remote consumer DR and consumption monitoring. This concept would be enabled by AMM infrastructure but will need legislative support and cooperation with DSO. This concept would be promising especially from the financial and energy consumer savings (chapter 3.4.5).

3.4.2 Renewable Resources of Electrical Energy (RES-E)

Renewable resources are in present days supported by massive public subventions and its installed capacity is growing. From the viewpoint of energy branch infrastructure they represent still young influence that could cause changes with dispatching and electricity transport. Moreover growing installations of ERS-E provoke changes in whole energy branch. Advantage is that they are using sources of primary energy that are today “limitless or self-renewable”. Its future unavailability is therefore not a risk. Potential of these sources is also very big and seldom used principles such as geothermal seem to be promising for the future. On the other hand the electricity generated in these devices is very expensive and installed capacity utilization is much lower than utilization of classical resources. Their unpredictably moreover cause serious problems for the stability of grid.

3.4.3 Improvement of Current Technologies

Improvement of current resources parameters would be done both in fossil as well as nuclear resources. The mentioned list is not exhaustive.

- **Resources with supercritical parameters:** These resources uses steam above critical point (above 22,055 MPa, 373,976 °C) [12]. Classical Clausius – Rankin cycle with supercritical steam has increased efficiency of electricity production. The mentioned parameters of steam however need massive investment into infrastructure of power plants, especially body of steam generator, distribution and turbine. The experiences from power plants shows however large unreliability, low availability and very expensive operation.

- **The new generation of the nuclear reactors**: It means IV generation of Nuclear Power Plants (NPP). The new generation of nuclear reactors would be able to convert thorium ^{232}Th and uranium ^{238}U to plutonium ^{239}Pu or uranium ^{233}U. This conversion is done in fast breeder reactors. The fission in these reactors is utilized by fast neutrons without moderation.
- **Carbon capture and storage** (CCS): It is a principle of storage of CO_2 which should help with minimizing of CO_2 emissions. In this concept the emissions are captured and stored immediately after they leave the power station. Problem is to find appropriate reservoir, mostly underground, which would be useful. Another problem is the fact that process of CCS is very demanding for energy. Therefore it decreases the efficiency of power plant.
- **Very high temperature reactor (VHTR)**: Represents the economical possibility of thermal production of hydrogen from the steam.
- **Usage of hydrogen**: Hydrogen would have very broad usage for example in accumulation of electricity, as very clean fuel for combustion engines and so on. Problem is that its production is not very cheap and there are a few problems left with manipulation and storage of this gas.

3.4.4 Brand New Technologies

- **The fusion reactor**: If the fusion reaction would be controllable, it would provide almost limitless resource of energy. The fusion reactor would have specific parameters. It would have very large capacity. From technical point of view is fusion still problem and its future success would require very long development.
- **Utilization of new resources:** These resources are e.g. thermal usage of shale gas or peat.
- **High temperature superconductors** (HTS): If the superconductors could hold its superconductivity in normal temperatures (0 - 100°C) they could be used for transports of electricity for long distances with low losses. At present there are no materials which could hold superconductivity except of very low temperatures. Therefore its massive utilization is today impossible.

3.4.5 Savings

Savings in general influence energy branch by influencing of consumption. Savings can be divided into two parts. The first are energy savings and the second are capital savings.

3.4.5.1 Energy Savings

It must be remarked here that savings represent large future potential. Mitigated consumption of electricity replaces necessity of its generation connected with possible pollution. Each saving represents resource of energy that does not need to be generated. Therefore it shall be mentioned as a Smart Technology. The energy savings can be done by more effective process of energy consumption as well as lower losses during energy production and transport.

$$SV_e = C_0 \cdot \left(svr_e (1 - svr_t) + svr_t \right), \tag{2}$$

where C_0 is consumption without savings purged from any other influences like economic cycle, svr_e is saving ratio of consumed electricity and svr_t is saving ratio of transported electricity.

3.4.5.2 Capital Savings

Capital savings can be caused by DSM or DR using high volatility of electricity. This savings will need implemented AMM that utilize end user appliances management (more in chapter 6.7.1). The accumulation potential enlarges potential of such savings.

$$SV_C = C_{manageable} \cdot \Delta p_e \tag{3}$$

where $C_{manageable}$ is consumption possible to be shifted according to electricity price, Δp_e is electricity price change (today represented by difference between base and peak load).

3.5 Current Financial Investment Methods Suitable for R&D

Capital is one of the most important aspects of ST implementation. The amount of necessary capital is obviously large. In the public discussion and in vast majority of studies relevant real calculations are missing. Each study has its sponsor and results can be mostly modified according sponsor's needs. Independent calculations will have to be provided by independent institutes e.g. research institutes. Each capital source embodies not only different amount of free capital but also different willingness for risk exposition and their behaviour is differently influenced by the global economic condition.

3.5.1 Structure of R&D Investment

As it is shown on Fig 5 the capital used for investment originates from different resources. The very first step of every brand new technology must be research, which is mostly financed from public sources[6]. These sources are not so sensitive on financial market situation because of larger “inertia” of public sources mostly represented by long-time funds. This capital originates from local public sources (e.g. local taxes) and also from international funds (e.g. EU funds). Important aspect is that this capital can be massively influenced by political decisions.

Next step is development conducted mostly by private capital (VC-venture capital and PE-private equity funds). This stage is important for future market penetration but still remains very risky for investors.

Manufacturing is the stage when consolidation of the market occurs. Strong and healthy investment of companies from “development phase” become more competitive. The largest obstacles are cost needed for manufacturing equipment. Only strong subject with sufficient capital can be effective in this phase. Therefore mergers and acquisitions (M&A) occur in this phase in the way of market penetration form strong players.

The last step is realization phase which makes use of credit through bank loans. Such investments are no more risky; therefore they become attractive for banks. On the other hand capital needs stays high because of marketing and market penetration costs as well as distribution costs. Additionally some subventions became more probable because of selective support by government.

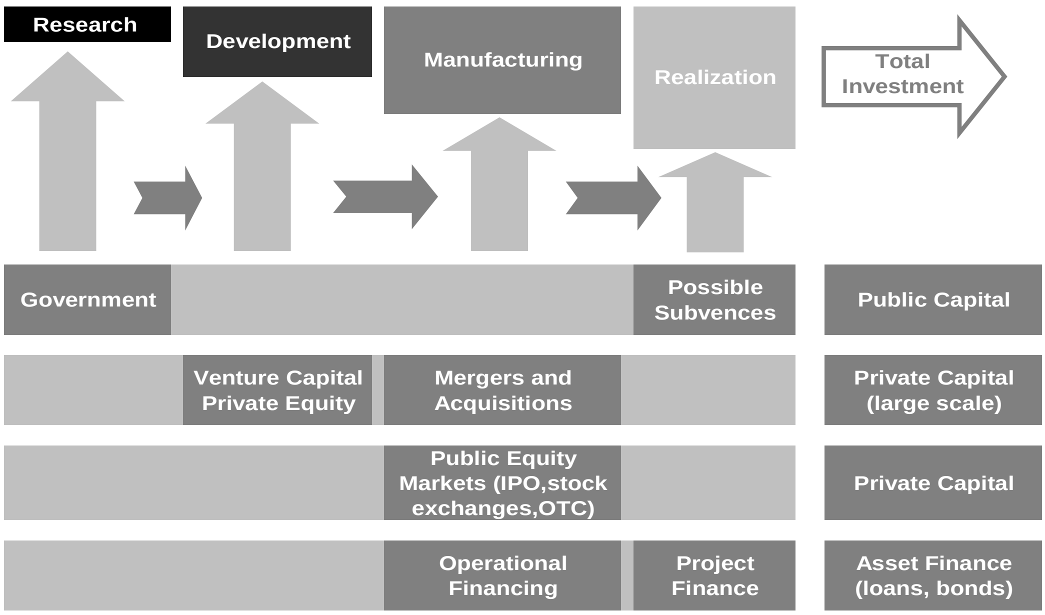

Fig 5. *Structure of capital during ST development and realization. Source [23] was modified and distended by author of this thesis.*

[6] Sponsorship is possible in the research phase as well but it is not so large experience with it from history. It became more important only in recent years and is much more dependent on economic cycle. The larger experience with these funds is e.g. in the area of pharmacy.

The following paragraphs show example of capital investment development into RES-E, energy efficiency and also in low carbon technologies projects.

- **Investment via Venture Capital and Private Equity.** It is truth, that the structure of invested capital has changed itself very much during last few years. During the recent period the economic recession appears but it has influenced the structure of capital invested via VC/PE not so massively. It is caused by large persistence in investment decisions and strategic plans of VC/PE investors. Different situation is with PIPE/OTC. OTC is actually a substitute to exchange. Therefore situation with OTC is similar to Public Markets.
- **Investment via Public Market:** Totally other situation can be seen regarding to economic recession with public markets. After massive, almost exponential growth between 2002 and 2007, occurred massive fall in 2008. This situation was caused by massive restlessness on the public markets, especially on the exchanges. The fall of prices was manifestation of mutual trust between market participants downfall. The segment of R&D was not an exception. The conclusion therefore is that capital originating in public markets is very sensitive to prevailing market sentiment.
- **Investment via Asset Financing:** AF represents an external capital, mostly originating in banks. This financing method is deeply influenced by higher deliberation of risk departments of all banks which appears mostly in syndicated loans. Opposite situation is with classic project finance. An accompanying phenomenon was also dynamic growth of interest rates, which according to official bank expressions represents higher risk surcharge.
- **Mergers & Acquisitions:** In the sector of M&A in general was no dramatic change. Again capital from public markets diminished but on the other hand asset acquisitions increased its share. This is caused because lot of healthy companies utilised the situation of cheaper assets for enlargement of its portfolios.
- **Loan Guarantee Fund:** It could be another kind of regulatory stimulation. It enables to spread the cheaper opportunities for obtaining the investment capital from bank loans. Because of risk mitigation some guarantees mostly brings cheaper capital.
- **Barter:** For example in France, where EdF builds Flamanville, the large industrial customers concluded consortium Exeltium. This consortium can pay some electricity in advance to support current CF of investors (EdF and ENEL). It obtains advantageous prices for

future electricity. This is an example of barter that can cause following savings for capital obtained from bank loans.

– **State Guarantee:** Risky for any future investment is future development of prices. State can for instance guarantee some price level where NPV of the project is for investor positive. When prices fall under this level the difference is paid by the state. On the other hand when price is higher the difference is paid to the state. This method is kind of sharing of profit. This method brings some kind of regulation of future investor's earnings (rent ability). Similar methods are used for RES-E support.

3.6 R&D and its Macroeconomic Aspects

The above mentioned paragraphs show difference between sources of capital, especially difference in its sensitivity to market sentiment and economic health. The public capital is subordinated to political mood. The corporate capital behaves very logically and it seeks opportunity for profitable investment. The external, bank capital is subordinated to risk management of particular banks and capital from public markets is highly influenced by the market sentiment (never minds if the sentiment and market behaviour is very irrational). PE/VC seems to have stable trend. The change in its structure is represented by movement from early stage VC to late stage VC. It is caused by risk elimination because company in very early stage is of course more risky.

3.7 Technological Learning

Technological learning represents phenomenon that influences capital distribution between market participants, i.e. elements of the system. Their infrastructure therefore sets transformation of system inputs as well as feedback of whole system. The theory of technological learning was described by Wright, P. (1936) who disclosed that the unitary costs decrease with growing of accumulated production for a constant percentage each dabbling of accumulated production. Afterwards lots of authors have described technological learning in the various sectors (e.g. aerospace industry by Irwin, D.,A.; Klenow,P.,J. 1994 [24]). The term learning by doing was established by Yeh and Rubin (2007).

The mathematical formulation of technological learning was done by Argote,L. and Epple,D. (1990) [25] and summarized in literature e.g. in [18].

$$Cost_{acc} = Cost_0 \cdot V_{acc}{}^{\Pi}$$
$$\log(Cost_{acc}) = \log(Cost_0) + \Pi \cdot \log(V_{acc}) \tag{4}$$

$$PR = 2^m , \tag{5}$$

where $Cost_{acc}$ is cost per unit, $Cost_0$ is cost of the first produced unit, V_{acc} is cumulative unit production, Π is experience parameter and *PR* is progress ratio (rate at which unitary cost declines of every doubling of production).

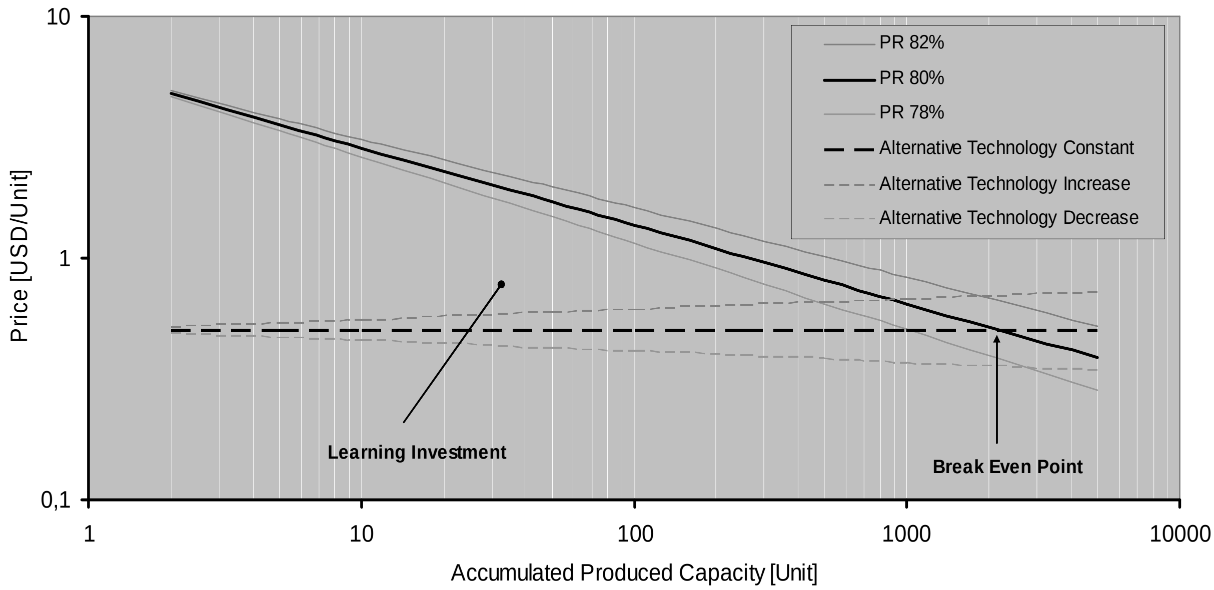

Fig 6. *Decrease of technology price in compare with an reference technology [18] was modified and distended by author of this thesis*

It can be seen in Fig 6 the decreasing price of learning technology should be compared to possible substituting technology. It must be mentioned, that during learning process of learning technology the price of alternative technology can change also, which is very important point which contributes classic theory of technological learning as it is mentioned e.g. in [18].

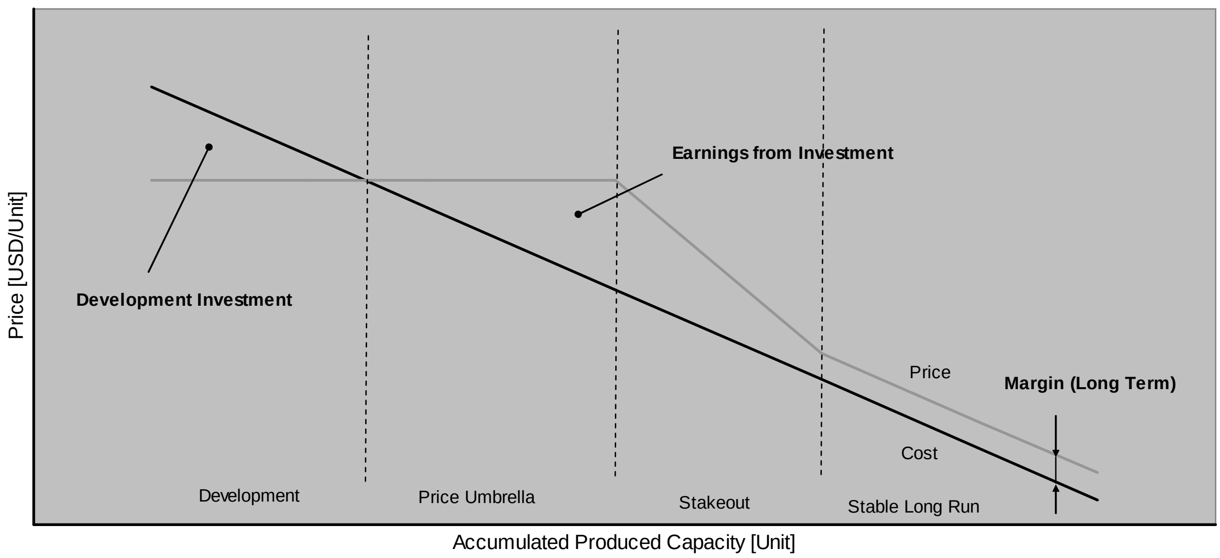

Fig 7. *Development of margin during learning process according BCG (1968)*

Fig 7 expresses common relation during lifetime of some technology. The d*evelopment* phase on this figure corresponds partly to *research* and mostly *development* phase on Fig 7. During *price umbrella* process the investor intends to obtain capital spend during development phase and also accumulate the capital for future. On Fig 7 it corresponds to *manufacturing* as well as *realization* phase. The rest of the lifetime is driven mostly by marketing and competition against substitutes.

According to opinion of author of this thesis the Fig 7 is without economic cycle impacts. During recession or during rapid economic growth the costs and prices could change rapidly. Especially recession during stakeout phase causes very strong descent of market prices because of market competition. (e.g. Czech photovoltaic boom where phase of stakeout was at the same time as crisis during that prices of costs decreases more dynamically which influenced also prices). More is mentioned in chapter 3.7.1.

The learning process can be also deviated by market regulation. For example in the period 1995-2001 in Germany the Feed-in-tariffs were too high [26]. The prices of wind power plants technology (costs for investors) were constant and in the same time in Denmark the prices of technology (costs for investors) decreased. Therefore prices were kept on high level near to price umbrella level. There was therefore no force to costs to fall and therefore costs were also constant. Therefore margin of contractors and its subcontractors became larger.

The situation is changed when future development is included. In the long run, the motivation can change itself into win-win strategy. For example massive support for electricity produced in photovoltaic power plants has already cost European electricity consumers millions of euros. On the other hand price of photovoltaic panels has decreased about ten times [27] since the 70´s (Fig 8).

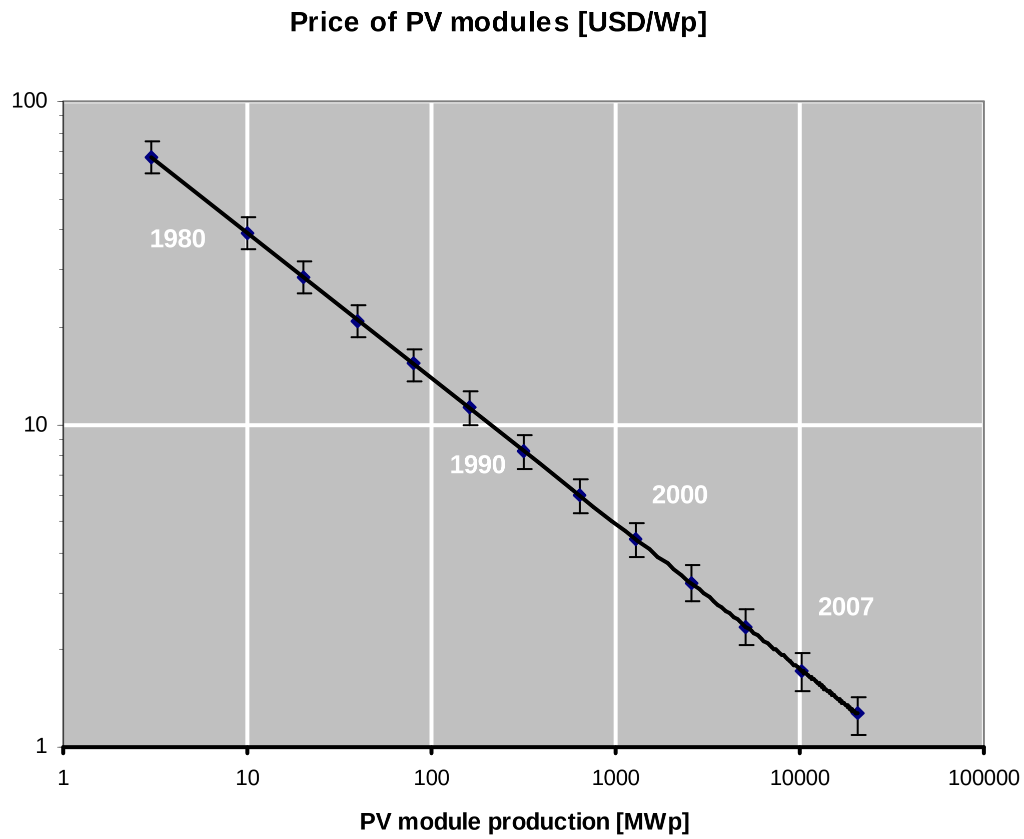

Fig 8. *PV modules price development depending up the production capacity [28]*

3.7.1 Case Study Technological Learning- Photovoltaic

For application of technological learning methodology on the sub-system of ST/SG there can be mentioned analogy with photovoltaic. These conclusions of technology learning process are apparent on the historic data of photovoltaic (PV) plants infrastructure costs. They are shown on Fig 8. The descent of CAPEX is on the figure apparent. In Czech Republic the feed-in tariffs were formulated in the year 2007. Moreover legislation established limits for feed-in tariffs adjustment. During year 2008 the global economic recession occurs. This following decrease of prices was intensified by stakeout phase of PV cells and marketing management strategy of PV producing companies that tries to adapt massive descent of feed-in tariffs in lots of countries. Lots of producing capacities were built and therefore excess of supply over demand have “pushed” the price lower. Price of silicon that decreases because of lower global demand underlines the descent of PV prices.

3.7.2 Case Study Technological Learning- Others

According [29] some slowing of learning rate (LR) is apparent during technology development. Some examples of PR are following: wind farms 0,805 ± 0,010 in Great Britain or 0,851 ± 0,016; bio-ethanol PR 0,832 ± 0,013; photovoltaic 0,794 ± 0,004.

According to [18] the PR may depend on the particular technology. In [30] distinguishes three types of technologies:

- **Modular technologies:** e.g. PV modules or some designs of complex power plants like Westinghouse AP 1000 reactor. The PR is typically in the range of 70 – 95 per cent.
- **Plant technologies:** e.g. power plants. The PR is typically in the range of 82 – 100 per cent.
- **Continuous processes:** e.g. production of chemical compounds. The PR is typically in the range of 64 – 90 per cent.

Experience with more complex systems like combined power plants reports independent learning processes for each part of the system. Therefore PR is higher. As an example can serve modern nuclear power plants units (NPP).

3.8 RES-E Support Principles Benchmark

It is speculative if RES-E can be involved between ST. According to author of this thesis the answer is yes. Their implementation was motivated by some of reasons mentioned in chapter 3.3. Some formats of RES-E support used in the EU are presented in this chapter.

3.8.1 Reasons for Support

It was mentioned above (chapter 3.1.2), that capital for RES-E support is obtained from electricity customers. It is very clear that such extra costs jeopardize purchasing power parity. Therefore reasons for such costs must be mentioned.

- **Externalities:** It was mentioned that internalization of externalities can bring future costs on today's market.
- **Technological learning acceleration:** The supports incentives demand for RES-E technology that accelerates accumulated produced capacity. According chapter 3.7 this brings technology CAPEX descent.
- **Public opinion:** In case of Germany or Japan after Fukushima, the power of public opinion is apparent. Both described cases represent public fight against NPP. As an alternative RES-E are afterwards supported. In the same time the paradox of mentioned public opinion is visible because the NPP represents very promising technology especially from point of global change mitigation because of low specific CO_2 emissions.

3.8.2 Public Resources Investment Subventions

Direct subventions are purposed to reduce CAPEX for investor into RES-E. Resources are public local or national budgets and allocation is set by some authority their founder is local municipality, national ministry government or the EU. This method does not represent correct motivation for investors because of lack of sustainability. We are witnesses of massive changes on the yearly basis which represents risk for investors e.g. from the view of utilization of already established supply chain etc.

This allocation method motivates investors in the way of large amount of installed RES-E capacity, not in the way of large amount of produces RES-E electricity. The allocating authority must guarantee, that subvention will be allocated only to investors with RES-E placed in suitable location from the province of authority according to physical principle of particular resource. In other words only investor that founds optimal regional location for the particular resource should obtain subvention. This should maximize availability of the resource and value of produced electricity.

During author´s research the situation dramatically tends to lack of public guarantees expected by commercial investors. The official opinions of large investors in analogical investments clearly show their conservative approach to infrastructural investments in EB (e.g. [31]).

3.8.3 Tax Concessions

Tax concessions improve earnings after tax (EAT) which promotes evaluations of net present values (NPV) of supported RES-E projects. That aspect motivates investors during pre-investment decision process pro evaluated project.

Similarly as method of investment subventions presented in chapter 3.8.2 tax concessions do not represent systematic approach. The tax legislation can be changed by government by political reasons.

3.8.4 Green Marketing

Green marketing utilizes third factor mentioned in chapter 3.8.1, public opinion. Traders have opinion to promote their electricity purchased exclusively from RES-E. Consumers can afterwards prefer such traders / electricity. Advantage is independence of this method on government. Problem is connected with large sensitivity on economic cycle. Subventions to RES-E electricity only according motto “*noblesse oblige*” would not survive some deeper economic crisis.

According to experience form USA summarized in [32] only 0,6% of customers manifest willingness to pay voluntarily more expensive “green” electricity. According to author’s opinion results in the EU would not be substantially different.

3.8.5 Systems of Electricity Prices Management

All electricity produced in some RES-E is purchased by trader or DSO[7] in the way to guarantee for RES-E some minimal specific electricity price. This fact promotes NPV of RES-E projects again. In general there are two methods

3.8.5.1 Feed-in Tariff

This system is utilized e.g. in: Denmark, Spain, Germany, France, Austria, Greece, Luxemburg, Nederland, Portugal, Czech Republic and Slovakia. This method guarantee minimal price of electricity anytime regardless electricity market of grid situation. The value of feed-in tariffs for each country is set by particular regulation authority. Both a parts subvention as well as market price is replaced by one feed-in tariff declared for specific interval (mostly one year) by regulation authority. Potential massive changes on yearly basis stay risky for supply chain of investors.

3.8.5.2 Feed-in Premium System

In that case premium is added to market part of price. This premium is paid again from funds obtained partly from electricity customers and partly from public funds similarly as in feed-in tariffs[8]. The difference is that electricity is purchased by trader that can use this electricity for its market portfolio. This system shall be therefore more effective for whole system according conclusions of chapter 4 because trader behaves in the way of earnings maximization as rational participant with sufficient information. According to this presumption it should utilize accurate prediction to minimize its volumetric risk.

3.8.6 Systems of Generated RES-E Volume

Subventions are in this support method represented by obligatory quota for customers to buy particular amount of RES-E electricity in some region. Capital for these subventions is obtained from public resources or from electricity customers but only those RES-E will be successful that will be competitive with their internal costs against other RES-E.

3.8.6.1 Tendering System

Quotas, set by government are filled by central government policy. RES-E investors attends tender for filling these quotas. Each RES-E therefore must win the market competition with concurrence. Therefore they are forced to push down the price bid to the tender. Successful bidder obtains contract 15-20 year’s contract. The

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[7] Depends on legislation or generator’s mood.

[8] The system was designed to collect capital from electricity consumers in the past. The value of funds needed for support is growing and therefore the system was reinforced by public funds.

experiences show that implementation of this thesis did not bring the expected installed RES-E capacity[9].

In Great Britain (GB) the Non-Fossil Fuel Obligation NFFO[10] was employed. Because of lack of penalization for RES-E that does not fulfill the obligation resulting from contract there were no incentives to RES-E operator to submit realistic bids and reality could be different. Capital for subventions (difference between market price and winning bidder price) is obtained from taxes and other public resources.

3.8.6.2 Tradable Green Certificates (TGC)

The government sets quotas for consumed green energy (in other words electricity from RES-E) in the country. These quotes represents obligation for all electricity customers and is determined by number of tradable green certificates (TGC) that must be purchased by these consumers. One TGC correspond with one unit of consumed green electricity. Each RES-E obtains number of TGC equivalent to produced green electricity. These allocated TGC are sold by RES-E operators on the market, where are purchased by customers (or traders for their customer portfolio). This guarantees demand for TGC on the market.

Practically the RES-E operator tries to sell TGC on the market. If demand is higher than supply the price grows and vice versa. The new investors represent the long-term marginal units with long-run marginal costs (LRMC). The current operators of RES-E have only short-run marginal costs (SRMC) without large investment CAPEX in their internal costs. Therefore only in case that TGC price (in the sum with electricity price) exceeds total internal costs (for new-built resources) the installed capacity of RES-E will grow. More about TGC is written e.g. in [33] or [34]. Tradability of TGC represents large advantage because of market optimization that sets revenues for RES-E operators[11]. This tradability need not to be limited by some national borders. The trading pool for more countries brings possibility for optimization on more global basis.

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[9] On the other hand the lifetimes of RES-Es are mostly about 20-30 years. Regarding to low OPEX impacts on these RES-E without fuel costs, the mentioned duration of contract provides sufficient guarantee according author of this thesis.

[10] This system is now replaced by system renewables obligation certificate ROC.

[11] In case that legislation allows concurrence between TGC from different kinds of RES-E the complex natural resources optimization would take place. The RES-E portfolio is afterwards optimized from geographical and climatic point of view.

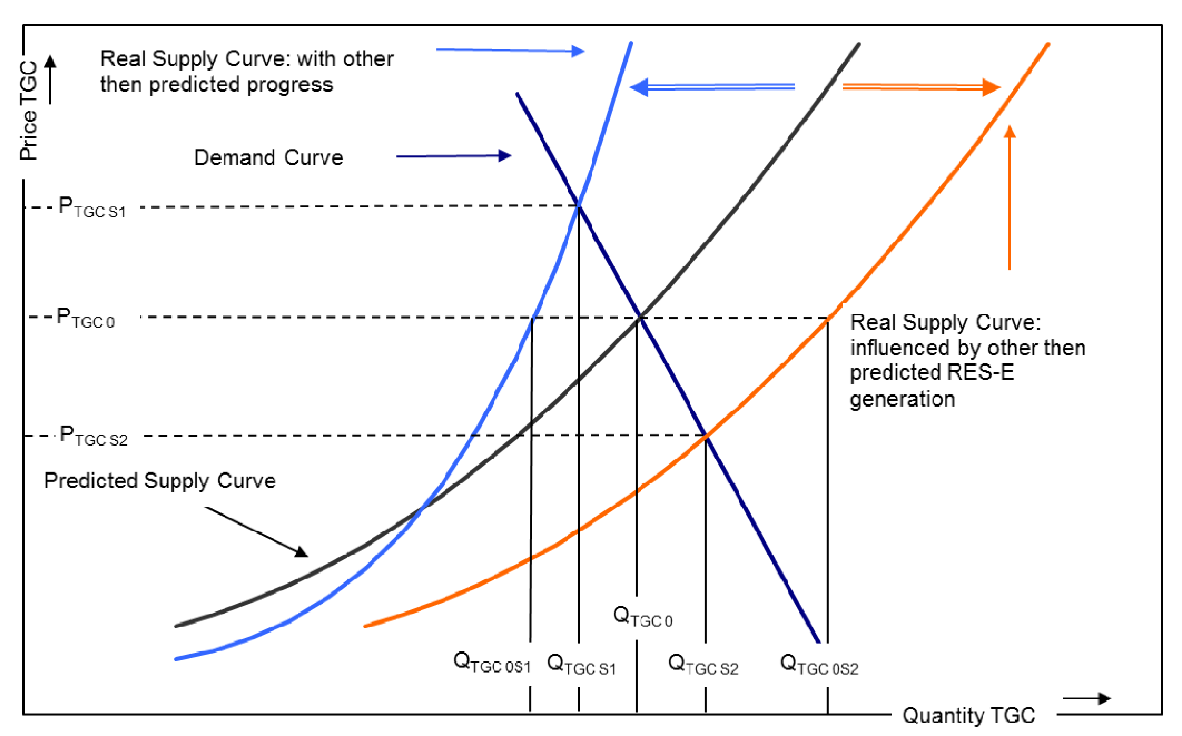

Fig 9. *Risk of bad supply curve prediction*

As it is described in Fig 9 the investor plans investment into RES-E according to market equilibrium set by predicted demand and supply curve. Demand curve is set mostly by macroeconomic forces and can be seen as *vice major*. Supply curve is influenced by concurrence. Investor predicts volume of TGC Q_0 and price P_0. The elasticity is predicted to be low. For predicted price $P_{TGC\ 0}$ the different amount of TGC ($Q_{\mathrm{TGC\ 0S1}}$, $Q_{\mathrm{TGC\ 0S2}}$) can be offered. The real value of TGC, set by market equilibrium differs ($Q_{\mathrm{TGC\ S1}}$, $Q_{\mathrm{TGC\ S2}}$) and particular prices are $P_{TGC\ S1}$ a $P_{TGC\ S2}$. Difference of revenues (ΔR_{TGC}) for RES-E operator set by equation (6) measures value of potential risk. Obviously the ΔR_{TGC} can be positive and negative as well but regardless that fat it represents investors risk.

$$\Delta R_{TGC} = P_{TGC\,S1} \cdot Q_{TGC\,S1} - P_{TGC\,0} \cdot Q_{TGC\,0S1} \qquad (6)$$

Methods of generated RES-E Volumes do not bring expected RES-E installed capacity according to author's opinion because of large risk for investors (e.g. presented in equation (6)). On the other hand according to author's opinion these systems represents better way of capital investment contributing to larger SWF. The direct management of prices as per chapter 3.8.5 provides large potential for mistakes under condition of unpredicted RES-E investment market development. Moreover regulation authority manages indirectly installed capacity to reach goals [35]. On the other hand the green electricity consumption is managed directly by methods presented in chapter 3.8.6, moreover by the means of market optimization. This optimization can moreover introduce concurrence between different kinds of RES-E which would represent regionally better allocation of capital.

4 Energy Branch as a System

In chapters above the smart technologies (ST) were described, the principles of financing applicable for these technologies were introduced and their application to RES-E segment was described. During research author of this thesis reveals most important aspect of ST implementation. This implementation exhibit attributes of system application. The pieces of evidence were described in this thesis many times. In chapter 3.3 the energy branch was described as a system. Sufficiency of future resources is influenced by resources portfolio as well as all other segments of economics. In chapter 3.8 the impacts of subventions to customers (their purchasing power parity) on the one hand and investors on the other hand were described and evidenced on the EU RES-E support schemes. These subventions are linked with accumulated production of some ST that contributes according to chapter 3.7 to investment CAPEX minimisation.

Situation in the power industry differs from lots of other industries. It is mostly caused by duality of this industry represented on the one hand by regulated and on the other hand by liberalized part (chapter 3.1). Therefore final electricity price for customers consists from two parts. One part is set by competition on liberalized market; the second part as a majority of the price is set by regulation authority.

4.1.1 Theory Application

In the following parts of chapter 4 author of this thesis describes application of systematic approach to energy branch in the intentions of ST as it was described above. The particular costs and benefits that represent inputs and outputs of SG implementation will serve for application.

4.2 Systematic Approach to Energy Branch

The attributes of system application is based on presumption that each impact (regardless of the fact that influences directly the customer or other market participant) represents finally benefit or cost for customer and to its social welfare (SWF). This idea is based on the fact that the customer is the final market participant who pays for not only market but also regulated part of electricity price. Moreover the relation between costs contributing to electricity price and costs for customer is not linear. Electricity price enters to all other goods and services cost-calculations and influence their market prices.

As it is shown on the Fig 2 there are internal mutual connections between the particular subjects in the power industry. This structure is valid under simplified presumption that it is isolated entity. The Fig 2 stays no longer complete when the power industry is situated into real economy / environment. Via some external connections (let it in general call motivation), the financial and electricity flows inside of the electricity market are influenced as well as outputs from this market to both natural and economic environment[12]. Fig 10 shows this second resolution of detail regarding system approach.

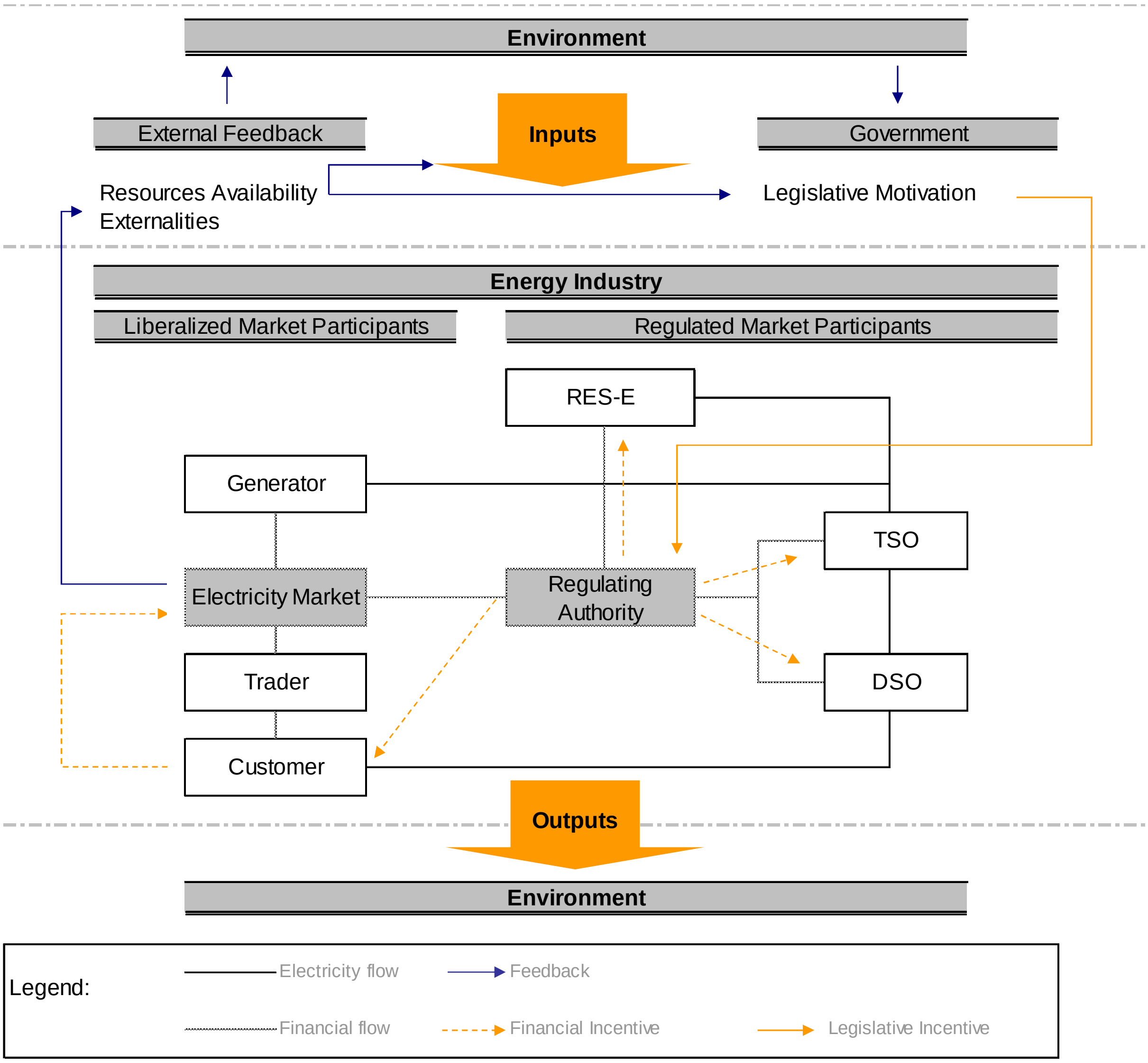

Fig 10. *System in the second resolution – energy branch*

For the correct methodology the author will suppose the Customer to be final investor of all ST system and related costs as well as final stakeholder of such implementation. Its market participation is clear and regulated payments will be considered to be paid by all electricity users (see chapter 3.2). Additional presumption is that Cash Flow point of view will be used for all mathematical theses in this work.

4.2.1 Description of the system

Energy industry system (EIS) is characterized as a group of elements interacting together [36]. The interconnections between internal subjects (according chapter2.3)

[12] Author of this thesis neglect other impacts, because they out of scope of this thesis.

are determinative especially for inputs transformation characterized by P_{trans}. Important for system stability is feedback that can report incentives from outputs to the inputs. The feedback shall establish stability of the system. Internal structure of participants (as described in chapter 3.2) in EIS sets the state variables ($\vec{S}t(t)$) and internal connections sets transformation process P_{trans}. The mentioned connections are following:

- **Logistic connections**: These connections serve for transport of energy in all forms from primary energy sources to the consumer. Energy could be, passing the logistic connection, transformed into another forms. It could be form of chemical energy in coal, oil or gas; thermal energy in the heat or electrical energy in electricity.
- **Financial connections**: As an integrating factor serves the trader. The majority of financial flows from customers flow through this subject. It could have relationship with all subjects on the market never minds if this subject is regulated or liberalized.
- **Communicating connections**: These connections serve for a data transport between market participants. Today the direction of these connections is mostly one way. This feature would be for many ST insufficient. The presumption is that in the future the advanced metering should establish conditions for both direction real time communication which would be useful e.g. for the instant grid regulation.

4.2.2 Inputs

Among the inputs from environment according Fig 10 are not limited to following:

- Physical aspects of resources of electricity and it's generation and transport
- Availability of natural resources (influenced by feedback chapter 4.2.5)
- Natural environment
- Social aspects: e.g. live style, demographic aspects, political aspects (for instance future prohibition of NPP in German energy industry mentioned in chapter 3.8.1), etc…
- Structure of consumption and consumption preferences (e.g. electric vehicles except of common cars with combustion engines)

4.2.3 Outputs

Among the outputs to environment according Fig 10 are not limited to following:

- Emissions (e.g. carbon or sulphur oxides, etc…)
- Import dependence on energy resources
- Availability of natural resources (influenced by feedback chapter 4.2.5)
- Externalities (influenced by feedback chapter 4.2.5)
- Impacts into natural environment
- Production by products e.g. waste, ash or slag; warm waste water; nuclear waste; landscape changes (e.g. mines or wind power plants) etc…
- Social aspects: e.g. purchase power parity of customers, life standard
- Possibility of future society/economy development

4.2.4 Environment of the System

The whole electricity market is integrated into the macro economy system (Fig 10). Environment for EIS can be divided into following parts:

- **Natural environment:** Features sets by physical conditions and attributes of whole planet natural system on the Earth.
- **Social environment:** Features sets by social attributes of society dependent no geographical position of region.
- **Legislation environment:** Features sets by political system dependent no geographical position of region.
- **Economic environment:** Other markets than energy ones.

It is also important to mention that environment sets limits for system development as well as for feedback according chapter 4.2.5. Also optimisation of system as per chapter 4.2.5.1 is set by these limits.

4.2.5 Feedback

Feedback determines sustainability of EIS (in the meaning of chapter 3.3). From author's point of view this feedback in the same time establishes possibility of EIS management. It is quite obvious, that feedback from today's regulation incentive appears with long time delay. Moreover aspect of massive inertia (chapter 4.2.5.4) of EIS according to author's opinion undermines thesis of effective allocation of capital on free market. Free market optimizes in the real time not regarding to future development. Incentives strategies from the future can be again provided only by the regulation (e.g. motivated by aspects mentioned in chapter 3.3) but such regulation must be qualified and contribute to SWF increment. Bad regulation can cause on the other hand massive SWF descent.

As it is shown in chapters 4.2.2 and 4.2.3 feedback establishes direct link between inputs and outputs. For future stability of EIS the feedback that reduces extremes (negative feedback) and guides development of EIS in the way of SWF growth is admissible. Therefore regulation of feedback represents possibility for whole EIS management. For this feedback regulation the author suggests following criteria.

4.2.5.1 System Development Criteria

According to author's presumptions development and regulation of EIS should be performed according criterion SWF optimization (chapter 4.2.5.3) which is linked with optimal structure of inputs and outputs as well as appropriate regulation that utilize feedback according chapter 4.2.5. Thanks to complexity of electric power sector is not trivial to find this optimum. Moreover we have only limited amount of control mechanisms originated from the legal system and regulatory authority. The governable part of inputs can be called as legislative motivation of market participants (Fig 10). This motivation in general sets boards and limits for all financial flows in the energy industry as well as scopes for particular market participants. Because of situation that the vast majority of financial flows are mutual between these market participants, the interests of one subject end where interests of another subject begin. Therefore motivation according to win-win strategy would be difficult to find.

The regulation can be performed by inputs and feedback (Fig 10). In my point it is important that local optimization represents not global optimization process in the same time which complies with literature [37]. Question is what constitutes the criterion of SWF. For my analysis the regulation via CF allocation in the EIS will be optimized according SWF criterion (chapter 4.2.5.3).

4.2.5.2 Economic Effectiveness

Before direct discussion about SWF the economic effectiveness criterion shall be defined. The economical effectiveness expresses basic advisability of some investment [38]. In the most trivial case it represents calculation (balance of future costs *Cost*(t) and benefits *B*(t)) with regard to the time value of money by classical *NPV* method [4].

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t}, \qquad (7)$$

where NPV is net present value of some investment, CF_t is cash flow in some year *t*, *r* is discount (time value of money) and *T* is lifetime of particular investment.

Refer to equation (7) the future *CF* is the most important aspect of the economic effectiveness. Therefore calculation of future *CF* represents the most important aspect of SG implementation. Such calculation would be utilized only by correct estimation of future cash costs *Cost*(t) and benefits *B*(t) regarding the evolution and liberalization of electricity market.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{(B_t(t) - Cost_t(t))}{(1+r)^t} \quad (8)$$

Where B_t is benefit of SG implementation in the year *t* to the customers, $Cost_t$ is costs of SG.

4.2.5.3 Social Welfare

The change of social welfare (SWF) from costumer's point of view can be expressed by equation (9). According to [39] the aggregate NPV for customers can influence the change of SWF. The relation depends on customers NPV change that was chosen by the author of this thesis as criterion for SWF evaluation. Therefore relation in equation (9) represents only the pure cash benefit for customers. Other aspects also important for SWF can be involved into NPV (for instance environmental aspects by the means of externalities).

$$\Delta SWF \approx \sum_{k=1}^{N} (NPV_{CUS})_k \ , \quad (9)$$

where ΔSWF is change of social welfare, NPV_{CUS} is net present value of benefits brought by SG implementation during its lifetime *T* to the customers.

4.2.5.4 Inertia of the System

According to specifics inertia of EIS has to be discussed. Legislative motivation must be done regarding to that fact. Vast majority of investments in energy industry have long lifecycles. Any structural change can be implemented with some delay[13].

[13] Sudden changes that jeopardize lifecycle of already invested capital underlines risk for investors. Risk increment represents cost for customers during higher risk exceptions of energy systems operators and can not contribute to SWF growth. As an example can serve decommissioning of NPP Jaslovské Bophunice V1 reactor done due to the EU requirements [40].

5 Principles of Motivation upon ST Implementation

The systematic analysis of EIS reveals during author´s research necessity of description of market participants motivation principles. Motivation related to feedback of the system. According to facts described above (chapter 4.2) methodology for implementation of some new technology into EIS must be formulated regarding to special conditions of this industry. It influences financial as well as logistic connections in the system (chapter 4.2.1) with impact on system feedback (chapter 4.2.5). It is also very clear that without appropriate regulation (chapter 3.1.2) and system description (chapter 4.2.1) optimal development of EIS (chapter 4.2.5.1) cannot be reached. It is also obvious that because of inertia of EIS and impossibility of real time market optimization regarding future parameters the qualified development control is necessary (chapter 4.2.5). The potential of such control is described in this chapter 5.

The motivation is according to author's opinion method that provides control without massive discontinuities. This control can be performed by the strategy of direct system legislative incentive that changes feedback as well as infrastructure of subjects. It is important to underline that any regulation and control should not be retroactive to provide for investors comfortable and predictable environment regarding their *bona fide* (good faith).

5.1 General Principles for Economic Motivation

It is written in literature and very obvious that each rational market participant behaves in the way of its utility augmentation. It is much more serious question what does utility for some market participant mean. Ultimate utility can according author of this thesis mean anything according particular market participant willingness. This ultimate utility comprises consequence not cause. Therefore the analysis must reach real basis of utility which is the only correct manageable criterion and the first cause of system development. Ultimate utilities of business entities (legal persons) differ from ultimate utilities of customers (physical persons). But on the other hand utilities for both groups are based fundamentally on *CF* basis in this thesis. It is necessary to set one important fundamental criterion to establish universal easy criterion for all market participants and therefore for whole system. The analysis of utilities, necessary for the correct model formulation, is set in this chapter 5.1.

5.1.1 Legal Persons Motivation

Legal persons (companies) are managed by their management. Management is board of physical persons motivated by shareholders of legal person (which complies e.g. with [41]). Their contracts mostly contain variable fraction of wage related to market value of the particular company. Therefore for legal person long term motivation (executively represented by its management) the NPV criterion (mentioned in chapter 4.2.5.3) can be deemed as ultimate utility. CF sets the cause for decision.

5.1.1.1 Free-Market Legal Persons Motivation

The behaviour of legal person's free-market participants is according to author of this thesis driven by market value added (MVA) maximization because of management motivation. This maximization is according to author set by following equations.

$$MVA = \sum_{t=1}^{\infty} \frac{EVA_t}{(1+WACC)^t} = \Gamma \cdot \sum_{t=1}^{\infty} \frac{ROIC_t - WACC_t}{(1+WACC)^t} \quad , \qquad (10)$$

where MVA is market value added, EVA_t is economic value added in some year t, Γ is capital invested into economic activity of the company, $ROIC_t$ is return on invested capital and $WACC$ is weighted average cost of capital.

$$EVA = EBIT(1-\tau) - WACC \cdot \Gamma \,, \; ROIC = \frac{NOPAT}{\Gamma} \,, \; NOPAT = EBIT(1-\tau) \qquad (11)$$

where $EBIT$ is earnings before interest and tax, τ is tax rate and $NOPAT$ is net operating profit after taxes.

Using the above mentioned equations (10), (11), (7) the fundamental relation of MVA on CF can be obtained.

$$MVA = \sum_{t=1}^{T} \left[\frac{FCFE_t - D\&A_t \pm nonCFC_t + Interest_t}{(1+WACC)^t} - \frac{\Gamma \cdot WACC_t}{(1+WACC)^t} \right], \qquad (12)$$

Economic Profit

Capital Charge

where $FCFE_t$ is free cash flow to equity in the year t, $D\&A_t$ is depreciation and amortization, $Interest_t$ is interest to be paid to the lender and $nonCFC_t$ is non-cash cost.

The mentioned equation (12) represents value increment from the shareholder's point of view. Under condition that preferences of company and its lenders and shareholders merges[14], the market value can be set (from project's point of view) by equations (13) and (14).

$$MVA = \sum_{t=1}^{T} \left[\frac{FCFF_t - D\&A_t \pm nonCFC_t}{(1+WACC)^t} - \frac{\Gamma \cdot WACC_t}{(1+WACC)^t} \right], \qquad (13)$$

[14] Lender can be according various ways of R&D support schemes (chapter 3.5) mostly legal person from environment of EIS. Principles mentioned in this chapter 5.1.1.1 are also usable for these lenders. Therefore *NPV* of lender from EIS environment relies on success of the company's project in EIS, therefore on *FCFF* maximization of company.

$$MVA = \sum_{i=1}^{n} NPV_i + \sum_{t=1}^{T} \frac{-D\,\&\,\mathrm{A}_t \pm nonCFC_t - \Gamma \cdot WACC_t}{(1+WACC)^t}, \qquad (14)$$

where $FCFF_t$ is free cash flow to the firm, NPV_i represents NPV of particular project and n total number of projects.

It is obvious that correct motivation is represented by total sum of NPV maximization. In the same time the growth of NPV must be larger than sum of capital charge and D&A.

5.1.1.2 Regulated-Market Legal Persons Motivation

Regulated market participants can reach only regulated earnings. Mostly the real value of regulated earnings is set by particular per cent of invested capital. The regulation is performed by regulation authority. In case of Czech Republic the regulation authority uses methodology of revenue-cap [19]. The regulation of e.g. DSO is set by exact methodology of earnings regulation [4] that is represented by following equation (15).

$$AR_i = AC_i + D\,\&\,\mathrm{A}_\mathrm{i} + \mathrm{AE}_\mathrm{i} + \mathrm{Quality}_\mathrm{i}, \qquad (15)$$

where AR_i are allowed revenues in the year *i*, *AC* are allowed costs in the year *i*, *AE* allowed earning in the year *i* and *Quality* represents quality of electricity retail reliability in the year *i*.

- **AC_i:** Real costs from recent (year *i-1*) escalated by appropriate escalation index which is set as a mixture of CPI and other indexes according to particular DSO methodology. Into this group the vast majority of AMM/AMI costs would have to be incorporated to establish correct motivation incentive for DSO.
- **$D\&A_i$:** Acceptable value of depreciation and amortization is also set by regulatory authority. Their real value originated in recent carried investment (year *i-1*).
- **AE_i:** Allowed earnings for some year originates in product of WACC[15] and regulatory assets basis (RAB) from recent period (years *i-2* and *i-1*). RAB is value of fixed operating assets [4].
- **Quality:** Bonus or penalization is ± 3%of AE. Values of quality index depend on system average interruption duration index (SAIDI) by the weight of 50% and system average interruption frequency index (SAIFI) by the weight of 50% as well. Standard value[16] of quality

[15] WACC is set by regulatory office as well. Current value is 7,133% [19].

[16] Set by regulation authority.

index ± 5% represents indifferent tapeline. Bonus (penalization) grows linearly between + (-) 3% and + (-) 15%. When quality index reaches + (-) 15% difference from its standard value the bonus (penalization reaches 3% of AE.

It is obvious that when AMM / AMI Investment cost is allowed as AC, the rational DSO is motivated to install it. By the means of SG (as it is written in chapter 6) concept the DSO can enlarge the other motivation criteria AE and Quality.

Other examples are RES-E generators. There have their MVA guaranteed by regulatory incentives described in chapter 3.8.

5.1.2 Physical Persons Motivation

As it is obvious in chapters 5.1.1 and 5.1.2 the NPV criterion is suitable for all market participants from generator to customer (participants described in chapter 3.1). The introduction to NPV criterion application to customer segment is provided in chapter 4.2.5.3. Author's presumption is that physical person behave in the way of growing utility and its utility can be measured by the means of NPV criterion as well. It is very important for author's analysis to norm all substantial aspects (SA) into levelized comparable criteria having one (monetary) unit. Group of these aspects contains all inputs, outputs, feedback and development criteria presented in chapter 4.

Important is that legal persons exists only in the EIS. The physical persons live in the environment of EIS. Therefore such aspect represents the most important difference between physical and legal persons utility. For physical persons, the NPV can measure their utility only limited by future externalities, system inertia and sustainable development.

5.2 Motivation as an Instrument

As it is mentioned above, the economical advisability is the most important constraint during the smart technology (ST) implementation process. Therefore each "smart idea" must be followed by the idea how to push it into the market and how to motivate the market participants to use this ST. The situation is therefore schizophrenic because every modern ST must on the one hand be technologically advanced and environmental friendly and on the other hand profitable for the majority of market participants. These are obviously antagonistic requirements because the quality must be paid by somebody.

5.2.1 Smart Grids legislation and Issues

Basis for European legislation framework is set by Essential Regulatory Requirements and Recommendations for Data Handling, Data Safety, and Consumer Protection Recommendation to the European Commission from June 2011. According to legislation 20% of customers should have AMM to 2020 in the EU. The motivation shall be therefore based on legislation.

Implementation of SG for some limited fraction of electricity customers shall bring benefits for all customers. It is problem to solve which way of motivation should be used to persuade customers. The most probable way therefore is global installation of AMM for all customers which must have support in the policy. This global implementation brings lots of risk to AMM users because it brings manipulation with lots confidential data.

5.2.2 Possible Contradiction of Motivation Instruments

Utility mentioned in chapter 5.1 for can cause opposite effect for different market participants. As an example could serve support of renewable electricity produced in renewable resources (RES-E). Electricity generation costs for generators are mostly much higher than the market price. The law incentives must therefore provide support for this electricity (see chapter 3.8). This extra capital is obtained from every consumer of electricity and is not subject to market optimization. This extra capital jeopardizes the SWF for customers and it is question if future impact to externalities will provide sufficient SWF increment as it is in chapter 5.1.2.

5.2.3 Global Criterion

As we can see above, the only way how to implement some new technology is to find the suitable way how to motivate the proper segment of the market and simultaneously don’t discourage some another one. In addition these two requirements are antagonistic in the most cases; therefore this represents great challenge for the implementation of ST to find such win-win strategy.

Only global optimization can represent appropriate development criterion to meet all participant motivation. As such global criterion the social welfare (SWF) for physical persons is the most relevant aspect. Only SWF growth can establish growing future market for the rest of EIS.

5.3 Methods of Motivation

It is obvious that any change of existing behaviour of participants must be motivated. The change of some regulatory policy or legislation constitutes change in redistribution of capital between particular subjects. Under typical market conditions is any change enforced by its indispensability because the market conditions should form the infrastructure market participants in the way to reach the optimal capital redistribution[17]. But in the case of electric power sector and implementation of ST, the physical indispensability (caused by externalities) which would provoke the change will appear in the future. Therefore this implementation represents situation when consequence overtakes the cause.

5.3.1 Free Market Incentives (Market Motivation)

The market motivation originates in market environment because these conditions represents actually real borders and limits for subjects on the market. Between these conditions belong among others prices of commodities, prices of technology and so on. The energy branch is only partly under free market conditions (chapter 3.2).

As it is seen on Fig 11 the market impact (in the same time incentive for participants) originates internally in the market and their first consequence on the EIS is marked by green colour on the Fig 11. They can originate in following aspects:

- **Market participant's behaviour**. Generation mix and Consumer consumption influences the market optimization massively. They influence directly position of market equilibrium.
- **EIS Inputs**. Inputs e.g. resource availability and natural aspects influence generation mix[18]. The consumer consumption is influenced by the economic cycle.

[17] This is correct according to universally used theory of capitalism and free market.

[18] The investor's investment into new resources is influenced by changes in input. As an example the Fukushima accident can serve. Natural seismic aspects (inputs) prevent all investors from possible future NPP on seismic unstable bedrocks. By this the local energy markets are influenced.

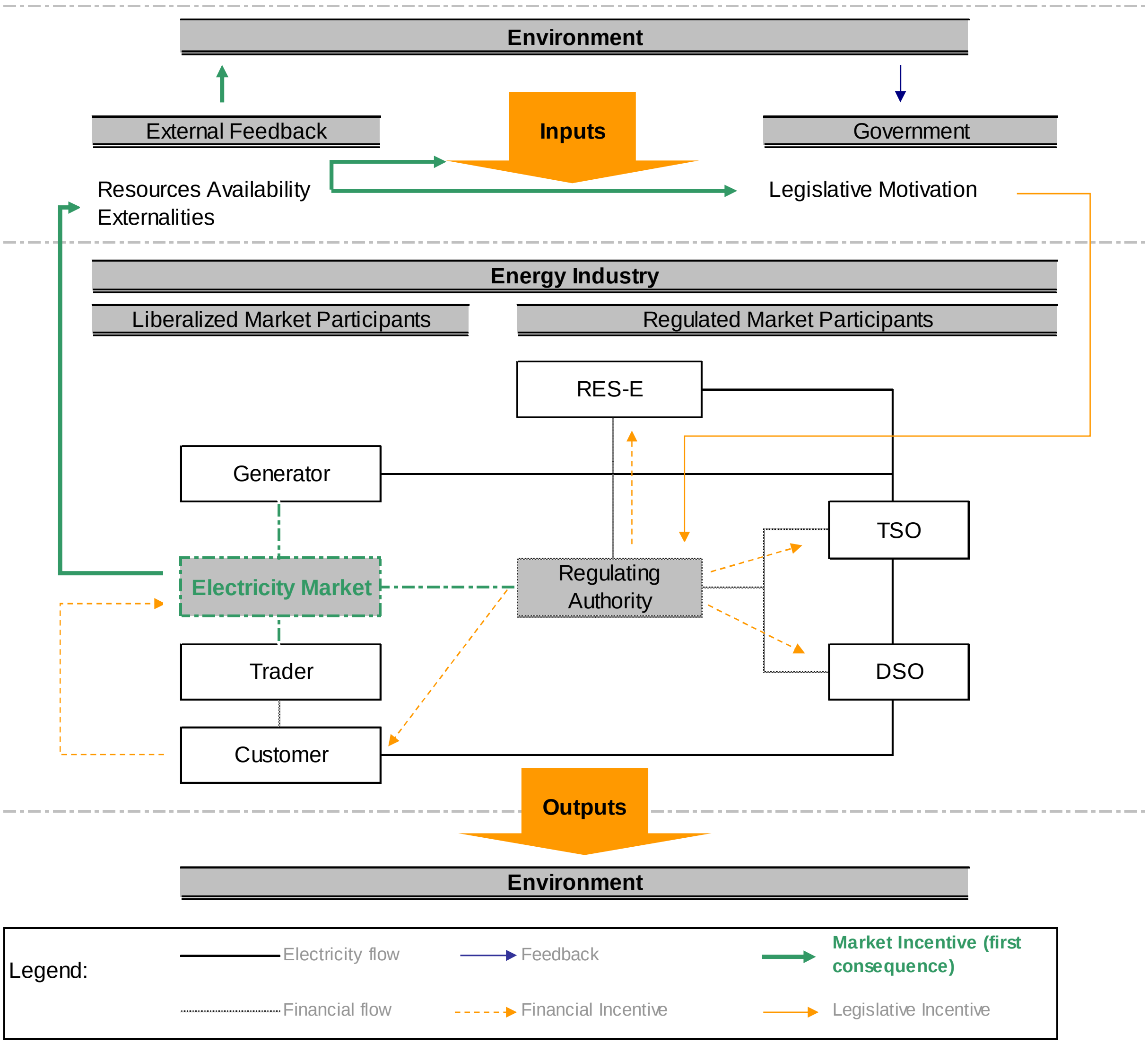

Fig 11. *Green-marked first consequence of market incentives impact*

The most important market incentive for participants and therefore for EIS entities is electricity price that influence electricity price for customers as well as generation resources mix. It is important that the market incentive influences only market electricity price which is (as it can be seen on Fig 3) minority of electricity price for the customers.

5.3.2 Regulatory Incentives (Regulatory Motivation)

The regulatory motivation is binding for segments of the electric power sector that are regulated by the regulatory authority. The influence of market is in these segments only mediated (more than first consequence therefore not green-highlighted on Fig 12). These segments are mentioned in chapter 3.1.2.

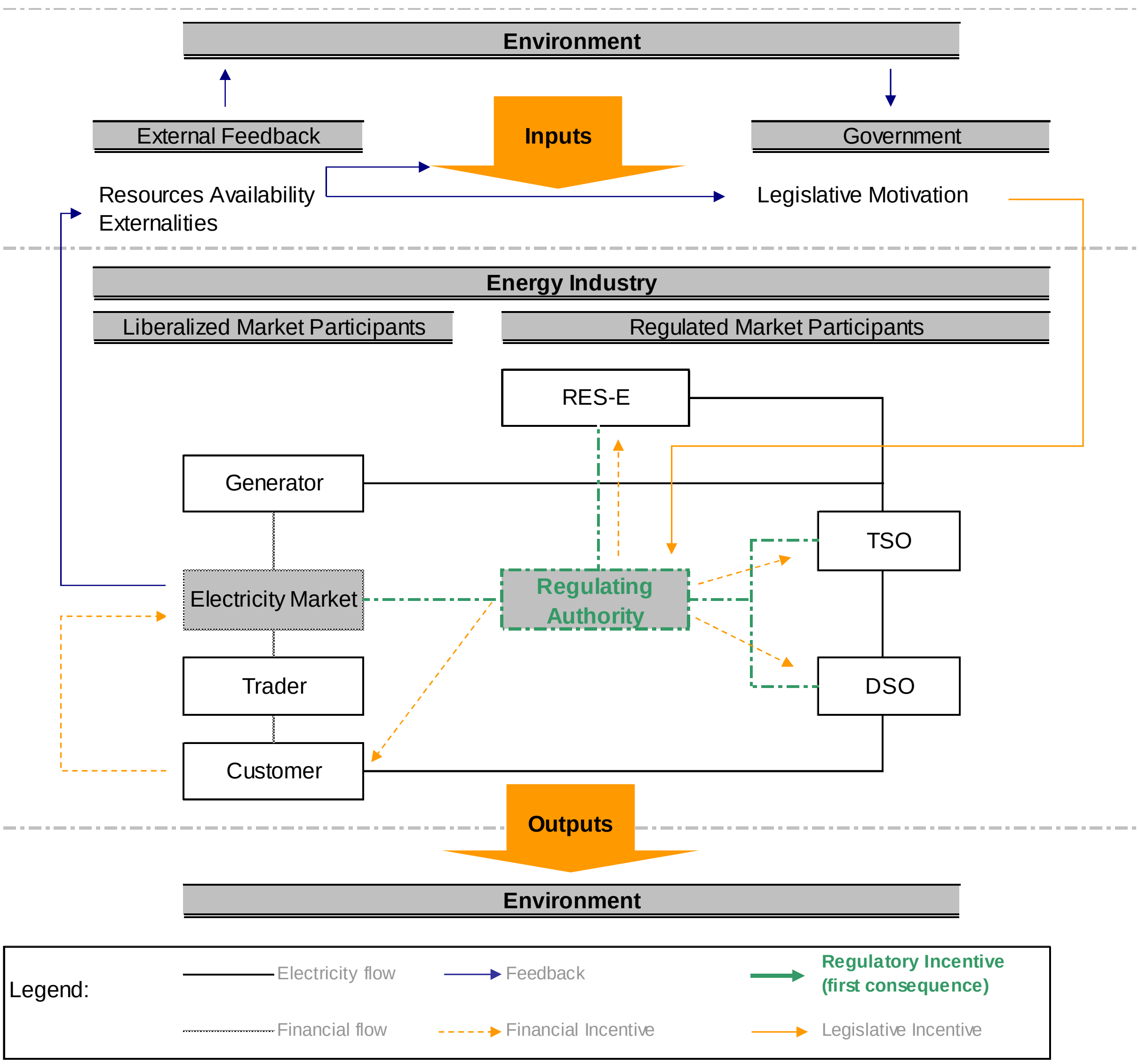

Fig 12. *Green-marked first consequence of regulatory incentives impact*

The regulatory motivation originates in regulatory authority based on legislation. Different support schemes (regulations) in the EU ensure values of the mentioned effectiveness criteria for the legal person motivation (chapter 5.1.1) high enough to motivate the investors to invest in the RES-E or maintain distribution system, etc. The substantial aspect of this regulatory motivation is that optimal capital allocation is not supported by market forces. As it is apparent on figure Fig 12 the regulatory incentives closely link to legislative ones. The regulatory incentives are in difference with legislation ones represented more by capital allocation formats. These formats consist of subventions for particular market participants. Value of subventions is dependent on the priorities, political desire and legislation.

6 Smart Grid Implementation Valuation

As it was mentioned above the systematic analysis is according to author suitable for energy branch description. Each system can be distinguished into more parts that can be described as subsystems. They appear to have the same characteristics as a macro system. This macro system represents for these subsystems environment. Author of this thesis used the systematic approach for SG (sub-system of EIS) description. Some important headlines in this chapter are added with appropriate role in the author´s systematic approach thesis, written in italic.

6.1 Brand New Concept of Decentralized Energy Branch

In the European Union (EU) predicted expansion of micro RES-E as well as electro-mobility will cause massive change in electric system stability. Today's grids and price management are designed according presumption, that large manageable resources transport electricity from high-voltage grids to low-voltage distribution grids. According to my opinion, such facts result in brand new approach to energy industry – decentralized energy industry which absolutely complies with implementation of SG. Moreover the system of new price management will have to be established under massive SG concept implementation as well.

Real time compliance between generation and consumption must be ensured to guarantee grid stability. Classical electricity resources that utilize some fuel represent resources manageable according to grid requirements. On the other hand some kinds of RES-Es are fully dependent on a climate conditions (non-manageable). Everyone knows the saying „you cannot command wind and rain“. Under condition of growing social welfare and current Western living standards we cannot accept its change into „adapt to wind and rain“. It is quite obvious that such a state would be absolutely unacceptable for both industry and households with. Impact of energy industry to social welfare is discussed in [42], [43]. SG can be simply described as a network which is at every moment able to respond to the current state in the grid [7]. Infrastructure that enables this concept is known as advanced metering management (AMM). AMM represents functional system of measuring devices with advanced functionality enables direct demand management as well as two way communications.

The advanced metering infrastructure (AMI) is more general concept involving other electrical devices, e.g. appliances, decentralized resources of electrical energy as well as system usable for customer behaviour regulation (demand response) [19]. This more advanced concept will represent necessary hardware basis for SG.

[19] It is very interesting that in Czech Republic remote control of demand exists for more than 30 years. It can be called 0th step of SG implementation. The device in the distribution grid which serves as transmitter transmits (under condition of surplus of electricity in the grid) impulse which is

6.1.1 Reasons for SG Implementation

There are some phenomena for that the former concept of electricity grids is not prepared. The most important reasons are those connected to natural environment as well as social welfare and macro economical. Only massive change of grid concept can establish change in the way of mentioned aspects. Detailed list of examples of such reasons is provided in this chapter 6.1.1.

6.1.1.1 Physical Reasons

- **Growing divergence between the production and consumption diagrams.** Today's electricity grids were designed according to presumption that generation of electricity is in real time managed according to consumption diagram. This fact is losing its validity with the growing amount of distributed RES-E resources. Generation in wind and photovoltaic power plants depend on local weather conditions, not on customer behaviour. Therefore uncertainty on the generation side must be considered by distribution system operators (DSO) or traders purchasing electricity from RES-E. In case of Czech energy branch the maximum/minimum of possible influence by 1 000 MW in photovoltaic power plant (PV) according to [44] is on the Fig 13.

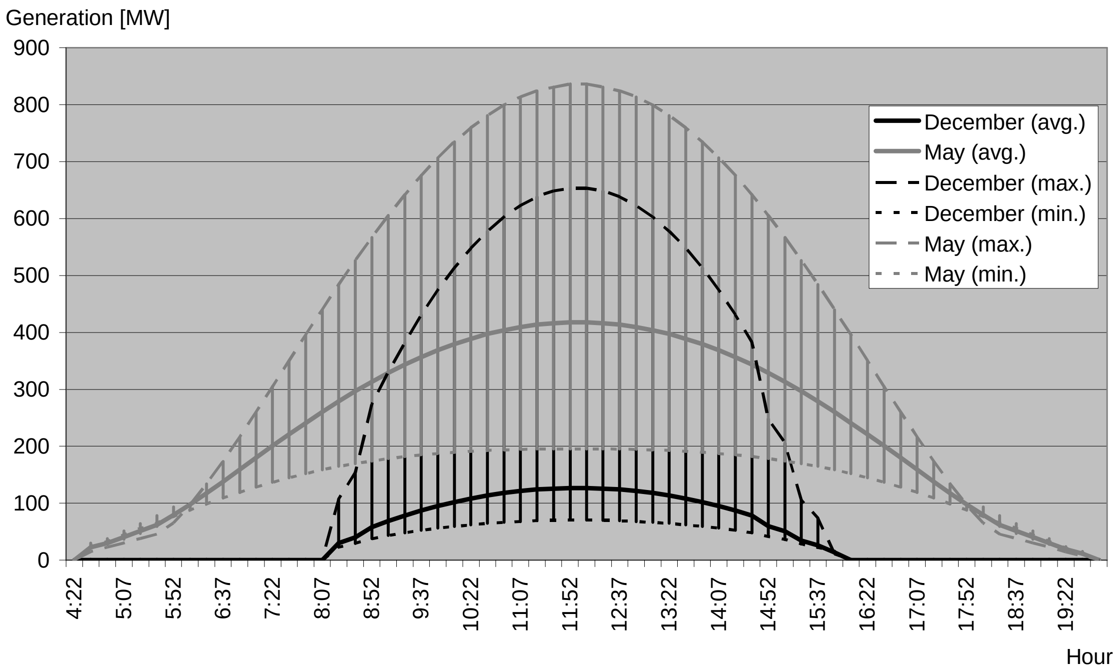

Fig 13. *Maximal, minimal and average daily uncertainty originating in 1 000 MW installed capacity in PV in Czech Republic (data PVGIS model [44]).*

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recognized in the consumption device. Such impulse switches accumulating heating. Similar impulse turns these devices off (when addition consumption is not needed). Disadvantage of this system is only one-way communication and especially this fact that it is not ready for accumulation and RES-E.

- **Growing divergence between the geographic location of production and consumption.** Maximization of RES-E availability factor forces investors to build wind power plants according to specific weather conditions, not according to grids requirements. Therefore large amount of electricity is transported via transmission grid [45].
- **Impossibility of storage is one of the implicit features of electricity.** This aspect influences especially electricity transmission and distribution. Under condition that vast majority of resources are manageable; generation is at any time managed according to consumption. Growing fraction of non-manageable resources represent incentive for electricity storage capacities [38]. The distributed accumulation is connected with penetration of plug-in electric vehicles (PEV). Their accumulators can be utilized for accumulation for the grid purposes as well.
- **Current orientation.** Today's grids are designed for electrical energy flow from large generation resources connected to high voltage parts of grid. In the decentralized energy industry the growing number of local micro generation could cause overflows from low voltage to high voltage grids.

6.1.1.2 Legislation Reasons

- **Any is connected with very difficult procedure of permitting procedure from side of land owners.** Therefore any investment into grid capacity enlargement (to avoid bottlenecks) represents very long and expensive procedure.
- **Growing amount of electric vehicles (EV).** This aspect can cause systematic overloads of current grids, as it is discussed in chapter 6.7.6.1.
- **The concept of SG / AMI should minimize mount of electricity transported via electrical grids.** The losses in today's grids are about 7%. AMI should therefore contribute to losses minimization.

6.1.1.3 Social Reasons

- **Socialization expands into all parts of human activity.** Connection and remote access represents issue. Consumer as a physical person wants to observe his consumption.

- **Savings contribute to higher level of effectiveness.** Optimization of consumption at any time can cause end user savings.

6.1.2 Decentralized Energy Branch as a Subsystem

In chapter 4 the systematic approach was described. This approach was chosen by author as a suitable approach for analysis of decentralized (distributed) power industry (DPI) and benchmark of AMI devices and whole SG concept. It is important to underline that DPI represents subsystem of EIS and that centralized global energy industry[20] (CGEI) comprises environment for DPI. Presumption for author's analysis is that centralized global energy branch system will be stable. Management of DPI by the means of SG concept only ensures that local grids will not cause instability that would be transmitted to higher voltage global grid. DPI supports in other words stability under condition of massive changes in the EIS as per chapter 6.1.

The environment for SG implementation is the power energy sector. The most important for SG implementation is not only the described market structure but also the legislation that establishes environment for utilization of market participant's motivation. Therefore it has direct impact on the feedback in chosen analogy with negative – feedback stabilized system.

Distributed or decentralized power industry will not be able to establish stability of the grid without stable global grids and functional mix of global resources, e.g. coal power plants, gas power plants, nuclear power plants and large RES-E will establish stability of global grid. DPI system therefore cannot be perceived as substitute to today's global grid large capacity resources.

6.1.3 Internal Features of the SG System

The SG represents not only brand new system of regulation but also brand new infrastructure which is sum of intelligent devices able to communicate both directions (from customer to distribution grid/trader and vice versa). The important motivation for its implementation would be in the near future inter alia savings originates from lots of aspects, e.g. impossibility of electricity storage, losses in the grids during transport of electricity (about 7%), possibility of decentralized RES-E or electro mobiles spread etc. as one example can serve the transaction costs.

[20] CGEI represents today the whole energy industry system without decentralized autonomously managed subsystems (local grids).

6.2 Aspects of SG Implementation

There are important aspects connected with new decentralized grids concept as well as with SG implementation. This chapter 6.1.2 provides list of such aspects.

6.2.1 RES-E Volumetric Impact

As it is mentioned above RES-E are components of decentralized EIS as well as SG concept. Considering the mentioned growing share of RES-E we logically come to the conclusion that growing percentage of generation becomes an independent variable, together with an increasing share of these non-manageable resources involved in the grid. Consumption, on the contrary would become partly dependent variable. The equations (16) – (18) are valid in closed system with no losses.

$$G'_{manageable}(t) = f_1\left(C'_{non-manageable}(t)\right) \quad (16)$$

$$C'_{manageable}(t) = f_2\left(G'_{non-manageable}(t)\right) \quad (17)$$

$$C'(t) = C'_{manageable}(t) + C'_{non-manageable}(t), \quad (18)$$

where $C'(t)$ is electricity consumption in the year t, $C'_{manageable}(t)$ is manageable fraction of consumption in the year t, $C'_{non-manageable}(t)$ is non-manageable fraction of consumption in the year t, $G'_{non-manageable}(t)$ is generation in non-manageable resources in the year t, and $G'_{manageable}(t)$ represents generation in manageable resources in the year t. Functions f_1 and f_2 represents relations between particular dependent and non-dependent variables and operand ´ (quotation mark) marks variable limited in closed grid.

Moreover large RES-E installations are mostly concerned to some areas with suitable weather conditions. Transporting capacity is in the same time strictly limited by physical conditions. This could under some unlike operational conditions result in congestion occurrence because only $G'_{manageable}(t)$ can be utilized as decentralized ancillary service (DAS)[21] according equations (16)-(18). Therefore electricity power transport, necessary for global grid stability, can be limited by such bottlenecks[22]. Mentioned fact will get worse with growing amount of non-manageable resources. This aspect could result in massive impact on the geographical electricity availability differences.

From long term strategic grid planning point of view the real occurrence of bottleneck depends on N-1 criterion fulfilment as it is described e.g. in [46]. The interruption of N-1 criterion can cause the virtual bottleneck. Overload of this

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[21] SG concept utilizes AMI as a mean for grid stability. Manageable resources included into AMI than serve as decentralized form of ancillary services. $G_{manageable}$

[22] In our approach the stability of local grid is discussed. Under condition of more local areas coupling the AMI can be utilized for stability of global area.

bottleneck results not in blackout but in interruption of N-1 criterion which massively jeopardizes grid stability in case of some additional not favourable event occurrence.

6.2.2 Local Grid vs. Global Grid

Moving to real (non-closed system), according to above mentioned facts (chapter 6.2.1) electrical grids naturally incline to decouple into more local grids by the growing amount of transported electricity.

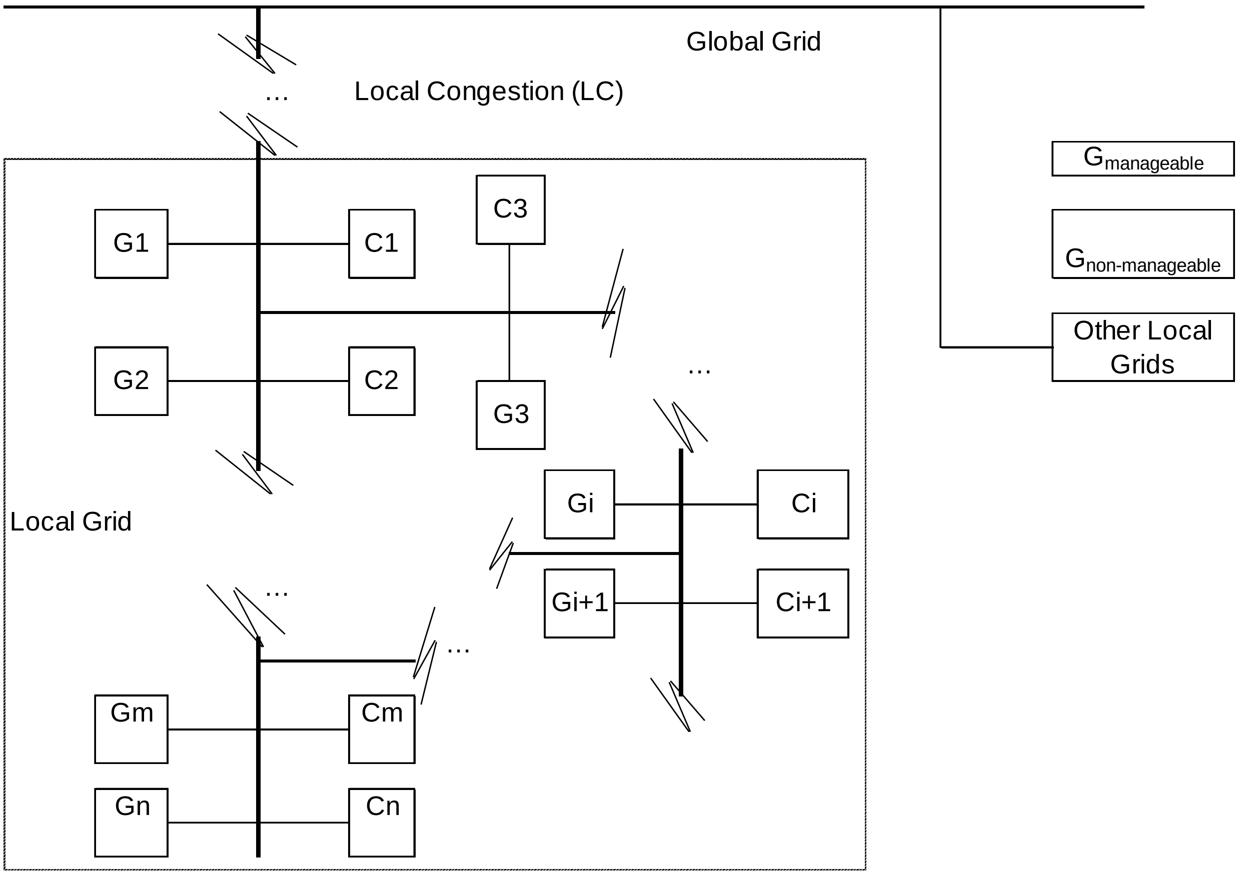

Fig 14. *Local electrical grid is element of global grid separated by congestion.*

Local grid for each customer differs. It is divided from global grid by nearest local congestion (LC). Regarding this fact the equation (19) would in real grid changes into following:

$$C^*(t) = G_{non-manageable}(t) + G^*_{manageable}(t) + G_G(t) - L(t), \quad (19)$$

$$G_G(t) \leq \mathrm{LCC} \quad (20)$$

where *C(t)* is maximal electricity consumption in some local grid, $G_G(t)$ is available generation capacity in global grid, $G_{non\text{-}manageable}(t)$ is generation in non-manageable local resources, $G^*_{manageable}(t)$ represents generation in manageable local resources, *L(t)* are losses in local grid and *LCC* is local congestion capacity. Operand * (star) marks time variable in real grid which can be managed by local AMM / AMI devices in the SG concept.

To be more specific this equation (19) is correct under condition of no congestions in the grids. To involve congestion the grid splits to more local grids. Example of local grid is on Fig 14. Bottleneck is caused by insufficient conductor capacity according to [20], [47]. This fact as well as exact value of *LCC* is set by physical conditions (according to conductors dimensioning methodology [20], [47]). In this case the condition (20) represents condition for equation (19).

6.2.3 AMM

It is obvious that management of local consumption is most important aspect of decentralized power industry. The equipment of AMM devices (AMI) is necessary but not the sufficient for successful SG concept implementation. SG concept in the same time is supposed to bring large savings by the means of AMM (e.g. dynamic load control as written in [48]). According to author´s opinion appropriate price management will represent the only way how to motivate consumer to behave (and manage his consumption) according to needs of the grid. It is not admissible to constrained consumers in their free consumption behaviour by ordering when and how much electricity are they allowed to consume. Therefore in this thesis the price management is proposed to serve as an appropriate method of demand management in the decentralized power industry. This fact requires moreover shift from AMM to AMI.

The change of social welfare (as per chapter 4.2.5.3) can be expressed by equation (21). According to [39] the aggregate NPV for customers can influence the change of social welfare[23].

$$\Delta SWF \approx \sum_{k=1}^{N} \left(NPV_{CUS}\right)_k = \sum_{k=1}^{N} \left(\sum_{t=t_0}^{T} \frac{B_t - Cost_t}{\left(1+d\right)} \right)_k , \qquad (21)$$

where ΔSWF is change of social welfare, NPV_{CUS} is net present value of benefits brought by SG implementation during its lifetime T to the customers, B_t are benefits of SG implementation in the year t to the customers, $Cost_t$ are costs of SG.

The most visible technical problem that remains according to technical experts during today's development of AMM devices is a digital noise from the grid, especially from low voltage (retail) part of the grid.

Following above mentioned methodology an instrument for grid management in the SG concept is $G^*_{manageable}(t)$. The question is from which point of view the management of consumption shall be made. Moreover connection of nodal prices and more effective capital allocation with social welfare has been described e.g. in [3].This therefore establishes multi criterion assessment of SG implementation. It is

[23] The exact relation depends on the value of externalities, because relationship in equation (21) represents only the pure cash benefit for customers.

important to underline, that costs of new AMM devices decline according to methodology of technological learning described in [18].

6.3 Electricity Price Impacts of Smart Grids

A very little discussed fact is that the management of AMM purely based on the needs of the network may not at any time represent the optimal management in the way of minimizing customer electricity prices. What the transmission and distribution system need is the equal balance of power to enable their operation. The resulting need for grid stability may not correspond with the needs of traders and consumers. Author's analysis is based on presumption that electricity price minimization together with load descent [49] represents incentives to social welfare increase because of fact that economic feasibility is set by customers savings (more in chapters 6.4.1 – 6.4.4) The price change, as an incentive to motivate customer to manage his consumption, will have to be made by AMI system connected in the smart trading system/platform (STS).

Moreover AMM (as a measuring part of AMI) would, according today's prevailing practice, represent expenditure for DSO. AMM infrastructure would be installed by DSO therefore it will represent their expenditure. The AMM devices would be involved in the balance sheets of DSO. The capital investment CAPEX connected with this would be according to today's manner obtained from consumers as an initial part of regulated price, as it is mentioned above in chapter 3.2. Moreover this source is timely shifted and spread to whole account lifetime of AMM devices. Cash for such devices on DSO's site is needed at the time of installation. This would need solution contains appropriate way of financing presented in chapter 3.5[24].

Aspects of new grid concept presented in chapter 6.1.2 are for purpose of this thesis by the author summarized and divided into two main impacts.

- The first impact, described in chapter 6.2.3 is necessity of brand new electricity grids management, mostly known as Smart Grids (SG) concept.
- The second impact is decoupling of prices from single zone to more nodal prices, described in chapters 6.2.1, 6.2.2.

The above mentioned facts result in massive changes in price management after SG implementation. The management of $C^*(t)$ should be made by the means of price changes (by AMI) according to chapter 6.2.3 in the way of higher consumer welfare. The following figures show principles of price and volume dependence by market

[24] The situation obviously differ according nature of DSO's owner (shareholder). Publicly owned DSO will be supported from public resources especially as per chapter 5.3. Private owned DSO will probably often utilize methods.

equilibrium. The following cases have in real grid not the same probability but in general all can occur. The following analysis was conducted regarding presumption of demand side management. Each case represents only one parameter change. Real situation will be accompanied by coincidence of more cases of grid situation.

6.3.1 Local grid consumption surplus

In case local consumption intends to transgress against equation (20) the grid stability can be ensured as follows:

Critical point is LCC transgress.

- Local generation $G^*_{manageable}(t)$ increase. This possibility can be used only in local areas where manageable resources (e.g, micro CHP) are presented. Such generation devices shall be therefore equipped by AMI management (STS).
- Consumption $C^*(t)$ decrease. The prices in local grid in that case decouples from global ones. Price increase must at any time ensure sufficient consumption decrease.

As it is shown on Fig 15, existence of *LCC* would cause price decoupling (ΔP) between local and global grid. Shown increment of consumer electricity price shall secure stability of the grid because local consumption will be changed from first stabilized state C_{g0} to Q_{g1} which is maximal volume of electricity that can be consumed without jeopardizing of grid stability.

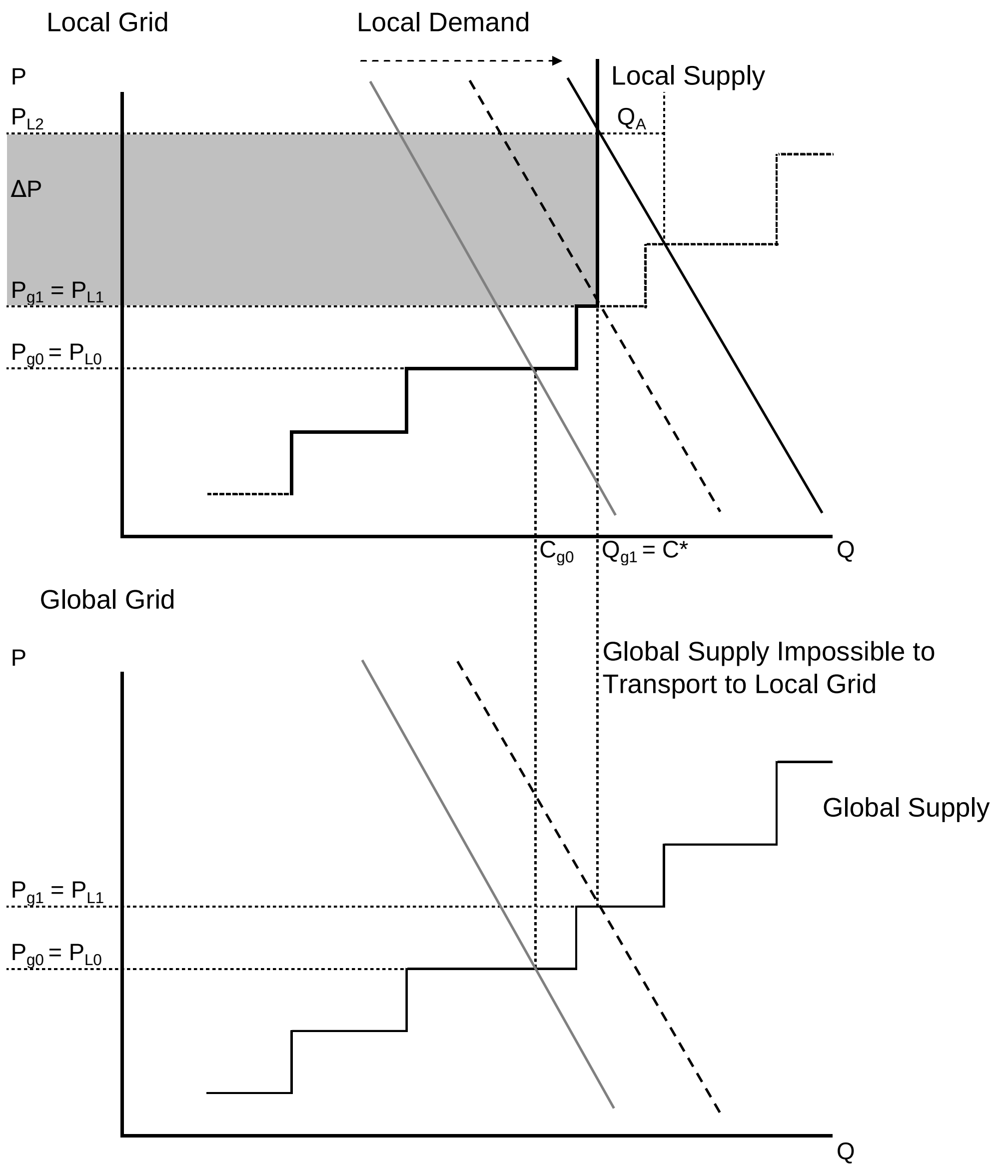

Fig 15. *Local grid consumption surplus*

Q_A represents avoided amount of electricity that would cause overload without AMM management. The dashed part of local supply curve is cut by AMI. Electricity price is changed by the market from P_0 price level to P_1 price level in both local and global grid. Price level P_{L2} is managed by the means of AMI and occurs only in local grid to secure grid stability. P_G is price in global grid.

6.3.2 Local grid generation surplus

LCC can be also transgressed by local generation, $G_{\text{non-manageable}}$ (*t*). In that case for grid stability there are following possibilities:

Critical point is production in local non-manageable resources impossible to export via LCC.

– Local generation $G^*_{\text{manageable}}$(t) decrease. This possibility can be used only in local areas where manageable micro generation is presented. Such generation devices shall be therefore equipped by AMM management as well as consumers.

– Consumption $C^*(t)$ increase. The prices in local grid in that case decouples from global ones. Price decrease must at any time ensure sufficient consumption increase.

As it is shown on Fig 16, existence of *LCC* would cause price decoupling (ΔP) between local and global grid. Shown descent of consumer electricity price will secure stability of the grid because local consumption will be changed from first stabilized state C_{g0} to Q_{g1} which is minimal volume of electricity that can be consumed without jeopardizing of grid stability.

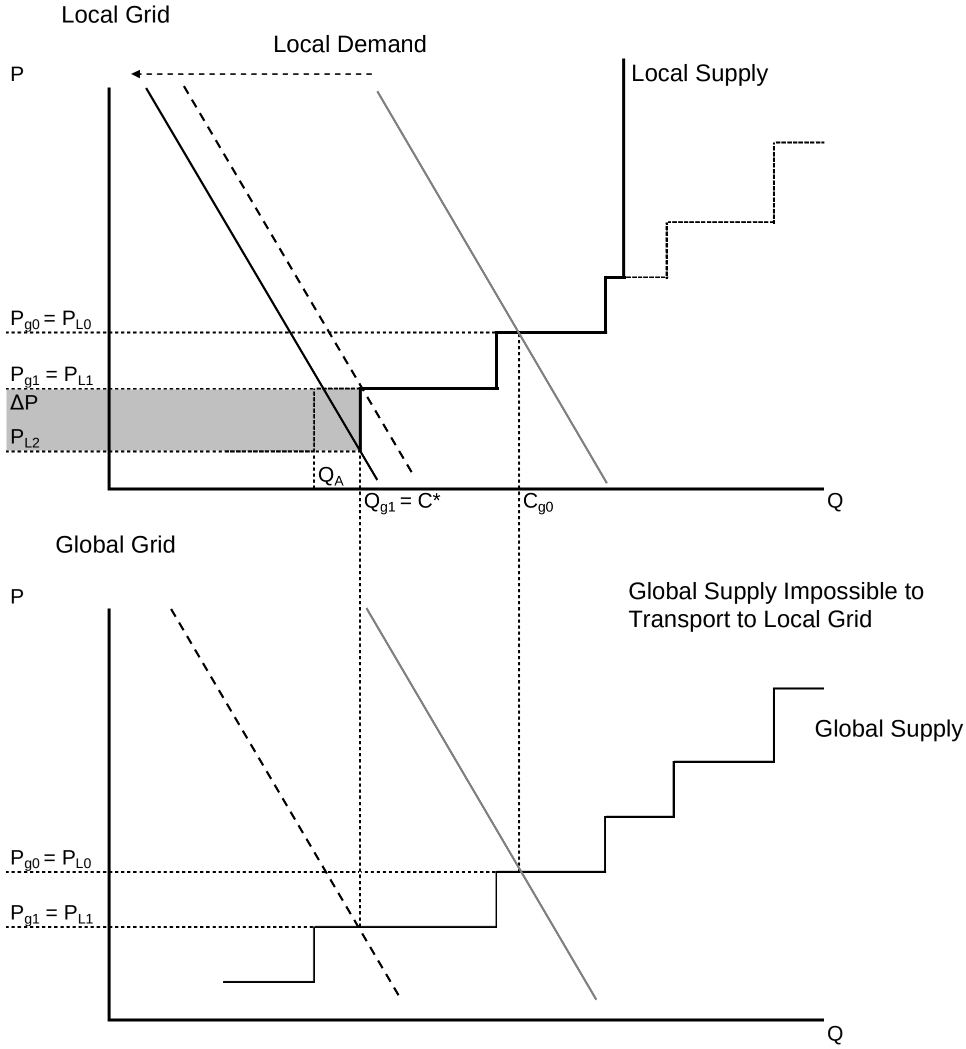

Fig 16. *Local grid generation surplus*

Q_A represents avoided amount of electricity that would cause overload without AMM management. The dashed parts of local supply curve are cut by AMM. Electricity price is changed by the market from P_0 price level to P_1 price level in both local and global grid. Price level P_{L2} is managed by the means of AMM and occurs only in local grid to secure grid stability.

6.3.3 Global Grid Generation Surplus

Another case is represented by situation when equation (20) intends to be violated by insufficient consumption in global grid. For grid stability there are following possibilities:

Critical point is LCC transgress in combination with global grid ancillary services capacity.

- Global grid generation shall be decreased. This response could be done by ancillary services descent or by management of resources (not only ancillary ones) equipped by AMM. I deal with presumption that ancillary services will not have to be equipped by AMM because they are managed by the needs of grid (by dispatching) according to the contracts with TSO.
- Consumption *C**(*t*) in local grid can increase only to the limit set by equation (20) to avoid overload of *LCC* capacity. Other local grids have also it's *LCC*. The maximal regulation potential is therefore set by sum of all congestion capacities of local grids. Additional increment of consumption when all *LCC* is used shall happen in other parts of global grid. This implies decrease of global price. Therefore price in local grid decouples again from global grid prices which decreases to stimulate consumption in other grids without congestion (with sufficient capacity).

As it is shown on Fig 17 below, existence of *LCC* would cause price decoupling between local and global grid. Shown decoupling of consumer electricity price will stop the growing volume of electricity consumption on level Q_{g1} which is maximal volume of electricity that can be consumed without jeopardizing of grid stability to consume at least local production and not to overload *LCC*.

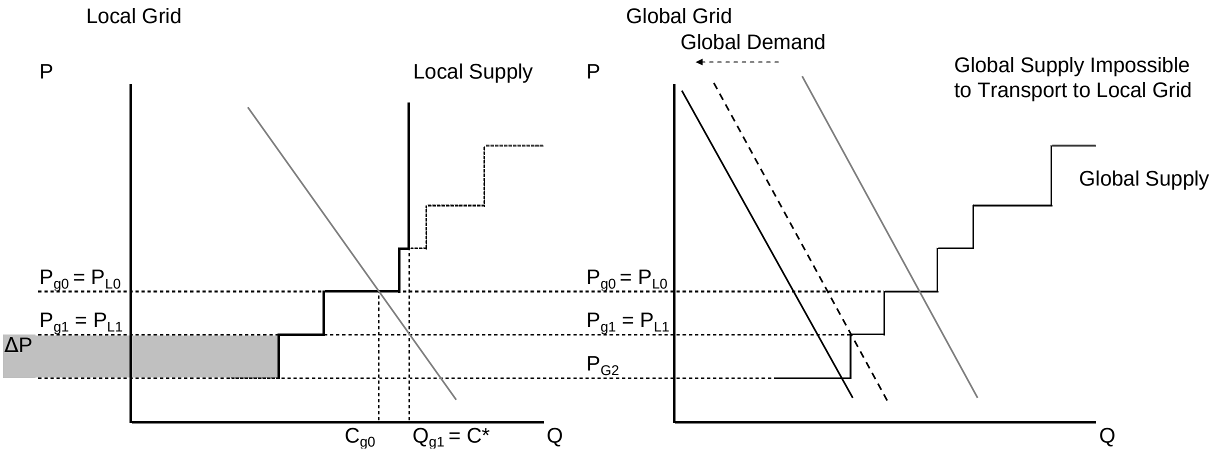

Fig 17. *Global grid generation surplus*

Electricity price is changed by the market from P_0 price level to P_1 price level in both local and global grid. Price level P_{G2} occurs only in global grid and by the means of AMM will not occur in the local grid to secure grid stability.

6.3.4 Global Grid Consumption Surplus

In that case all manageable resources will have to increase its generation.

Critical point is production in local non-manageable resources impossible to export via LCC.

- Decentralized micro generation shall increase. Limit for maximal possible regulation from (decentralized micro generation resources) is set by local *LCC*. In other words sum of *LCC* of all local grids set again the maximal regulation energy provided by decentralized manageable micro generation resources equipped by AMM (not their aggregate capacity).
- In the same time resources connected to global grid equipped by AMM devices shall be forced to increase their generation as well as ancillary services.
- Consumption in all local grids shall decrease in the same time to help with market equilibrium achievement. This can be caused by price increase in all local grids.

As it is shown on figure below, existence of *LCC* would cause price decoupling between local and global grid. Shown decoupling of consumer electricity price will stop the growing volume of electricity consumption on level Q_{g1} which is maximal volume of electricity that can be consumed without jeopardizing of grid stability to consume at least local production and not to overload *LCC*.

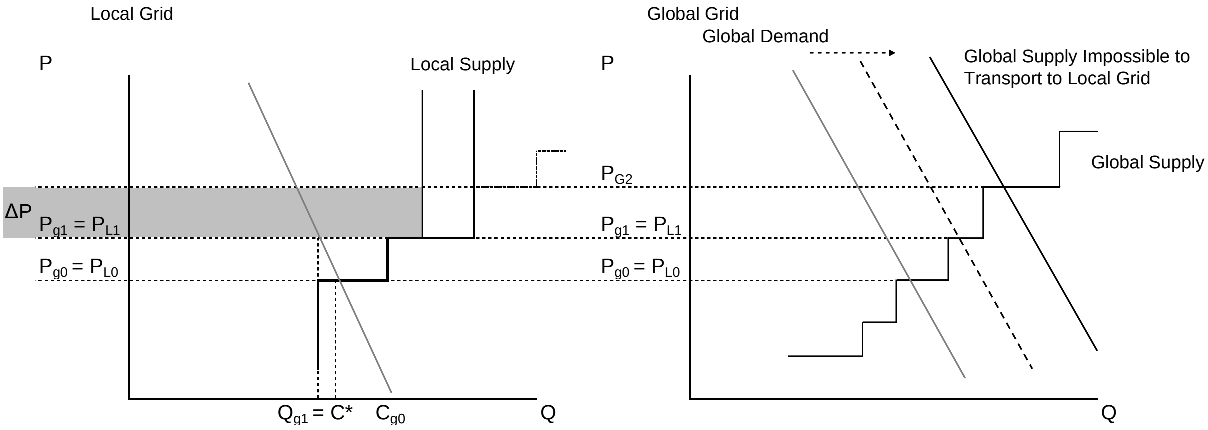

Fig 18. *Global grid consumption surplus*

Electricity price is changed by the market from P_0 price level to P_1 price level in both local and global grid. Price level P_{G2} occurs only in global grid and by the means of AMM will not occur in the local grid to secure grid stability.

Transportation of large electricity amounts (originated in local surplus of generation), increases probability of congestion in the grid. The situation can be therefore improved by consumption escalation in near local grids. This could cause price regional gradient of retail price which was described in Chapters 6.3.1 - 6.3.4.

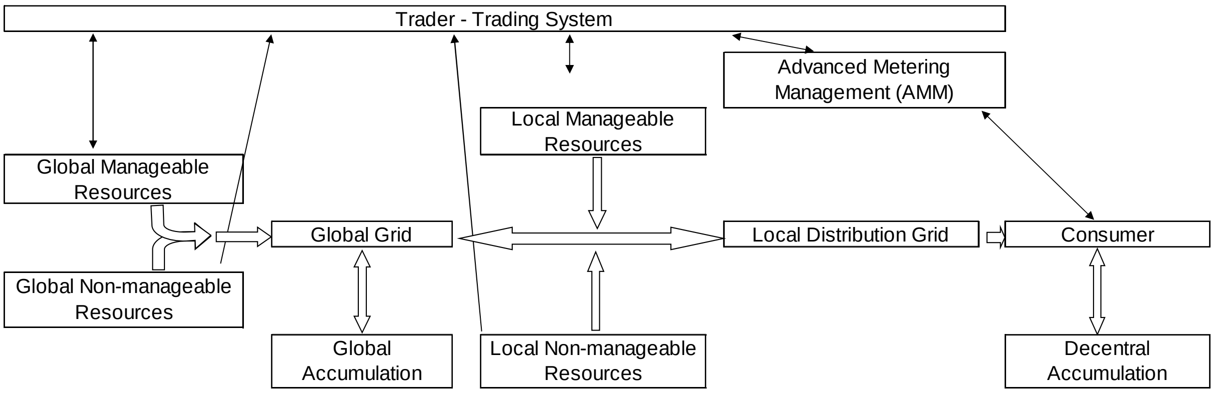

Fig 19. *AMM in the SG concept.*

6.4 Financing and Economical Effectiveness of Smart Grids – Cost Benefit Analysis (CBA)

In fact, SG concept represents a change of today's energy branch system. Therefore calculation of any effectiveness must represent a calculation of differences between today's energy industry system (EIS) without developed sub-system of decentralized power industry (DPI) and future EIS with implemented sub-system (DPI) therefore sub-system with incorporated SG concept. The chosen systematic approach described in chapter 4 needs detailed description of economical inputs and outputs applicable to effectiveness calculation described in chapter 4.2.5.1.

6.4.1 CAPEX inputs into SG system

These investment and other costs occurring in the beginning of DPI and SG operation have mostly capital character. Therefore they can be called CAPEX costs. These costs as system inputs are timely shifted from SG benefits as outputs. Therefore appropriate way of financing method shall be employed for that.

– **Threshold investment into SG infrastructure I_0:** The largest value of investment will be spent on advanced metering management (AMM) / advanced metering infrastructure (AMI) devices development, installation (incl. eventual reconstruction of electricity distribution by the customers etc…) and introduction into operation. Related are investments into communication and measuring system, or SG management and administrative SG departments of Distribution System Operators (DSO).

$$I(t)_{AMI} = \sum_{i=1}^{n} I_{AMI\,i} \tag{22}$$

$$I_{AMI} = \sum_{t=1}^{k} \frac{I(t)_{AMI\,t}}{(1+d)^{t-T_D}} \tag{23}$$

$I(t)_{AMI}$ represents total AMI costs in the year *t*, *n* represents number of AMI devices invested in the year t, I_0 is global discounted investment into AMM during *k* years which represents number of SG implementation years, d is discount rate (time value of money) and T_D is year to which discounting is performed.

– **Interim investment into state of the art maintenance of SG system I_I:** It is very clear that future moral maintenance of the SG system will need lots of capital expenses[25]. The maintenance investment not only repairs but also future investment into most developed technologies that would be available to keep the AMM / AMI system modern and up-to-date.

$$I_{It} = \sum_{t=1}^{T} \frac{I(t)_{It}}{(1+d)^{t-T_D}} \tag{24}$$

I_{It} represents total discounted interim state–of–the–art costs in the year *t*, *T* represents number of years during particular AMM lifetime and $I(t)_{It}$ represents interim costs in the year *t*.

– **Financing capital costs that originate from selected methods of financing C_{Debt}:** Capital costs connected with financing of AMM devices implementation. These costs mostly represent time value of external capital constituted by risk bonus connected with margin of the lender.

$$C(t)_{Debt\ t} = D(t)_t \cdot (i_{it} + rm) \cdot (1-\tau) + E \cdot d \tag{25}$$

$$C_{Debt} = \sum_{t=T_P}^{T} \frac{C(t)_{Debt\ t}}{(1+d)^{t-T_D}} \tag{26}$$

$C(t)_{Debt\ t}$ are capital costs in the year *t* C_{Debt} are total capital costs, $D(t)_t$ represents residue of external capital (principal) in the year t which is time variable, $i_{i\ t}$ is inter-bank interest (mostly EURIBOR) in the year *t*, *rm* is risk margin which contains risk bonus and margin for the lender, *E* is value of investor's equity, *τ* is tax rate (in country where particular investment is performed) and T_P is beginning of pre-operation investment period.

[25] Such costs can be called CAPEX operating.

– **Costs into establishment of marketing communication and market share possession C_M:** Represents investment for AMM / AMI producers and sellers. They represent investment connected with market penetration, marketing or communication.

$$C_M = \sum_{t=1}^{p} \frac{C(t)_{Mt}}{(1+d)^{t-T_D}} \tag{27}$$

C_M represents total discounted marketing and market penetration costs, $C(t)_{Mt}$ represents marketing costs in the year t and p in this equation number of years necessary for market penetration.

6.4.2 OPEX inputs into SG system

These costs occurring mostly during operation of AMI have mostly operating character. Therefore they can be called OPEX costs. These costs as system inputs are not timely shifted from SG benefits as outputs. Therefore the suitable way of financing can be found in continuous payment system amortized in the real time from SG benefits.

– **AMI communication costs C_{AMI}:** Costs originates in the way how communication between AMI devices is performed. These costs depend on the chosen communication channel.

$$C_{AMI} = \sum_{t=1}^{T} \frac{C(t)_{AMIt}}{(1+d)^{t-T_D}} \tag{28}$$

C_{AMI} represents total discounted AMI communication costs, $C(t)_{AMI\ t}$ represents communication costs in the year t and T lifetime of SG concept in described framework.

– **Operating costs of AMM devices C_{OP}:** Means operating cost, e.g. costs of spare parts replacement, AMI devices repairs, long term service costs, wear and tear etc…

$$C_{OP} = \sum_{t=1}^{T} \frac{C(t)_{OP\,t}}{(1+d)^{t-T_D}} \tag{29}$$

C_{OP} represents total discounted AMI operating costs, $C(t)_{OP\ t}$ operating costs in the year t and T lifetime of SG concept in described framework.

6.4.3 Benefit outputs from SG system

– **Benefits of increased price of energy produced in RES-E $B_{RES\text{-}E}$:** Is higher price of electricity that has for today's market low price because of its unreliability and long term unpredictability. For smart customers such electricity would have higher price because of possible time shifting and demand response.

$$B(t)_{RES-Et} = \sum_{i=1}^{m} \left(Pe(t)_{RES-E\_SG\_i} - Pe(t)_{RES-E\_i} \right) \quad (30)$$

$$B_{RES-E} = \sum_{t=T_0}^{T} \frac{B(t)_{RES-Et}}{(1+d)^{t-T_D}} \quad (31)$$

B_{RES-E} represents total benefit of electricity price increase T_o date of start of commercial operation of SG concept, $B(t)_{RES\_Et}$ benefit of the year t, $Pe(t)_{RES-E}$ is price of particular RES-E electricity without SG concept is implemented and $Pe(t)_{RES-E\_SG}$ is price of particular RES-E electricity under condition SG is implemented.Number of kinds of RES-E is expressed by variable m.

– **Decrease of necessary amount of grid regulation service B_{REG}:** Today's situation needs lots of grid regulation (by ancillary services) to keep the transmission and distribution system stable. AG concept can eliminate a necessity of some investment into grids (chapter 6.1.1).

$$B_{REG} = \sum_{t=T_0}^{T} \frac{C(t)_{REGt} - C(t)_{REG\_SGt}}{(1+d)^{t-T_D}} \quad (32)$$

B_{REG} is benefit of decreased costs for grid regulation services, C_{REG} represents costs of regulation services without SG and C_{REG_SG}. represents costs of regulation services with SG.

– **Benefit of various consumption monitoring $B_{integration}$:** Future integration of monitoring of various commodities (e.g. electricity, gas, heat or water) at end consumers. This monitoring would safe personal costs and also non-technical losses (stolen electricity).

$$B_{integration} = \sum_{t=T_0}^{T} \frac{B(t)_{integration\,t}}{(1+d)^{t-T_D}} \quad (33)$$

$B_{integration}$ is total benefit of various consumption monitoring coupled under SG and $B(t)_{integration\ t}$ is benefit of various consumption in the year *t*.

– **Benefit of cross-border monitoring $B_{Monitor}$:** Better monitoring of cross-border flows after implementation of high-voltage SG would be able to replace today's not so far successful Flow-Based Allocation (FBA) model and contribute to market coupling in the way of realistic trading regarding real regional demand / supply (chapters 6.3.1-6.3.4). This will according to author of this thesis enable larger transport capacity available for electricity transport by the means of flow reliability margin (FRM) minimisation[26].

$$B(t)_{monitor\ t} = p(t)_e \cdot \left(Q(t)_{crossborder\_SG} - Q(t)_{crossborder}\right) \quad (34)$$

$$B_{monitor} = \sum_{t=T_0}^{T} \frac{B(t)_{monitor\ t}}{(1+d)^{t-T_D}} \quad (35)$$

$V(t)_{crossborder}$ is volume of electricity transported without SG concept, $V(t)_{SG\_crossborder}$ is volume of electricity transported after SG concept implementation, $p(t)_e$ is electricity price, $B_{monitor}$ is total benefit from cross border monitoring and $B(t)_{monitor\ t}$ is benefit from electromobility utilization in the year *t*.

– **Implementation of brand new intraday price changes (smart tariffs) that would motivate the customer to move consumption (e.g. demand response, load shifting). B_{Market}:** Such an intraday price changes connected with motivated load shifting represent opportunity for traders to construct brand new products according to their actual portfolio and for customer to minimize costs paid for electricity. The examples and application of such management is presented in chapters 6.3.1-6.3.4 Avoiding of consumption during peak hours represents savings for customers.

$$B_{market\ t} = \sum_{h=0}^{8760} Pws(h)_h \cdot \left[p(h)_{e\_peak\ h} - p(h)_{e\_offpeak\ h}\right] \quad (36)$$

$$B_{market} = \sum_{t=T_0}^{T} \frac{B(t)_{market\ t}}{(1+d)^{t-T_D}} \quad (37)$$

Pws(h) represents power shifted by the means of demand response, $p(h)_{e\_peak}$ is electricity price during peak hours (“high smart price”) in the hour *h*, $p(h)_{e\_offpeak}$ is electricity price during off-peak hours (“low smart price”) in the hour *h*, B_{market} represents total benefit resulting from demand side management and $B(t)_{market\ t}$ is benefit of demand side management in the year *t*.

– **Avoidance of future investment cost into transmission and distribution grid infrastructure, necessary without SG concept. $B_{Inv.D/TSO}$:** Future development and maintenance of grids would not be possible without massive investment, especially under condition of future growth of electricity consumption (connected with economic growth) and mentioned RES-E influence (chapter 6.1.1).

[26] This margin is used by TSO as a security capacity to ensure grid stability.

$$B_{inv.D/TSO} = \sum_{t=T_0}^{T} \frac{B(t)_{inv.D/TSO\ t}}{(1+d)^{t-T_D}} \tag{38}$$

$$B(t)_{inv.D/TSO\ t} = Cost(t)_{inv.D/TSO\ t} - Cost(t)_{inv.D/TSO\_SG\ t} \tag{39}$$

$B_{inv.D/TSO}$ is total benefit from transmission and distribution system investment avoidance, $B(t)_{inv.D/TSO\ t}$ is benefit from transmission and distribution system investment avoidance in the year t, $Cost(t)_{inv.D/TSO\ t}$ are costs into transmission and distribution system without SG concept in the year t and $Cost(t)_{inv.D/TSO\_SG\ t}$ are costs into transmission and distribution system with SG concept in the year t.

- **Benefit of accumulation utilization B_{acc}:** SG would be necessary for effective way of accumulation implementation. Benefits of accumulation utilization are associated with B_{market} and $B_{RES\text{-}E}$ Accumulation supports height of RES-E electricity price as well as volume of shifted power *Pws*. In other words this aspect spreads time during that mentioned benefits B_{market} and $B_{RES\text{-}E}$ are applicable (equations (31), (37))
- **Benefit of illegal consumption avoidance B_{ill}:** Illegal consumption will be monitor able after SG and AMM implementation. This benefit is associated with $B_{integration}$.

6.4.4 Optional outputs from SG System

Some outputs represent optional future benefit. Its valuation depends on future market conditions. Today it can be evaluated by price of the option. More about options valuation it is written in literature, e.g. [50].

- **Benefit of electromobility utilization B_{MOB}:** Electromobiles or hybrid cars represent real option (alternative) to classical today's cars. SG implementation would be needed if electro mobility would spread between customers in the market[27]. Today's grids would have not sufficient capacity (chapter 6.7.6.1).

$$B_{MOB} = \sum_{t=T_0}^{T} \frac{B(t)_{MOBt}}{(1+d)^{t-T_D}} \tag{40}$$

B_{MOB} is total benefit from electromobility utilization and $B(t)_{MOB}$ is benefit from electromobility utilization in the year *t*.

It is mentioned that B_{MOB} represents necessary issue for real SG benefits valuation. Its applicability is set by following criterion.

[27] Real valuation of benefit B_{MOB} represents issue for real SG operative testing in the future.

$$I_H + I_E - I_C < \sum_{t=0}^{T} \frac{(C_C - C_H) \cdot p_{Ft}(t) + C_E \cdot p_{Et}(t)}{(1+d)^{t-T_D}}, \quad (41)$$

where I_H is the investment into hybrid vehicle, I_E is investment into necessary equipment for plug-in charging, I_C is the investment into classical vehicle, C_C is the consumption of classical vehicle, C_H is the consumption of hybrid vehicle, $p_{Ft}(t)$ is the price of fuel in the year t (which is function of time), C_E is yearly consumption of electricity by PHEV, p_{Et} is yearly average price of electricity (function of time) T is the life time of the vehicle and r is discount rate.

– **Benefit of mutual concurrence between various energy commodities $B_{\text{concurrence}}$**: Integrated measuring would utilize concurrence between energy commodities, e.g. electricity, gas or heat[28]. By the consumers the various kinds of energy converters would be installed. Such devices would utilize concurrence between e.g. electricity and gas because gas can be transformed by the engine (Combined Heat and Power - CHP) into electricity (with by-product heat or coldness). Under some market conditions this conversion could be beneficial at least at some hours during day of year. The following interpretations consider real time price monitoring and quantify potential of this conversion.

$$B_{concurrence} = \sum_{h=0}^{8760} \left(\begin{array}{l} p(h)_e \cdot Pw(h)_e + p(h)_g \cdot \dfrac{Pw(h)_{th}}{\eta_{th}} - \\ - MIN\left[p(h)_e \cdot Pw(h)_e + p(h)_g \cdot \dfrac{Pw(h)_{th}}{\eta_{th}} ; p(h)_g \cdot \left(\dfrac{Pw(h)_e}{\eta_e} + \dfrac{Pw(h)_{th}}{\eta_{th\_e}} \right) \right] \end{array} \right), \quad (42)$$

$$B_{concurrence} = \sum_{t=T_0}^{T} \frac{B(t)_{concurrence\ t}}{(1+d)^{t-T_D}} \quad (43)$$

where $B_{\text{concurrence}}$ is benefit from various energy commodities shifting, $p(\text{h})_{\text{e}}$ is real time price of electricity in the hour h, $p(\text{h})_{\text{gas}}$ is price of gas in the hour h, $Pw(\text{h})_{\text{e}}$ is consumption of electricity in the hour h and $Pw(h)_{\text{th}}$ is consumption of heat in the hour h (all time variables on hourly basis). Efficiencies are as follows: η_{th} is efficiency of heat production in Decentralized Combined Heat and Power (DCHP) without simultaneous electricity production, η_{e} is efficiency of electricity production in DCHP with simultaneous heat production and $\eta_{\text{th\_e}}$ is efficiency of heat production in DCHP with simultaneous electricity production[29].

[28] B_{MOB} represents example of more general benefit $B_{\text{concurrence}}$.

[29] Presumption is that all customer´s heat is produced by gas.

The time axis is set in the figure Fig 20. It depends on when the exact time to which discounting is performed.

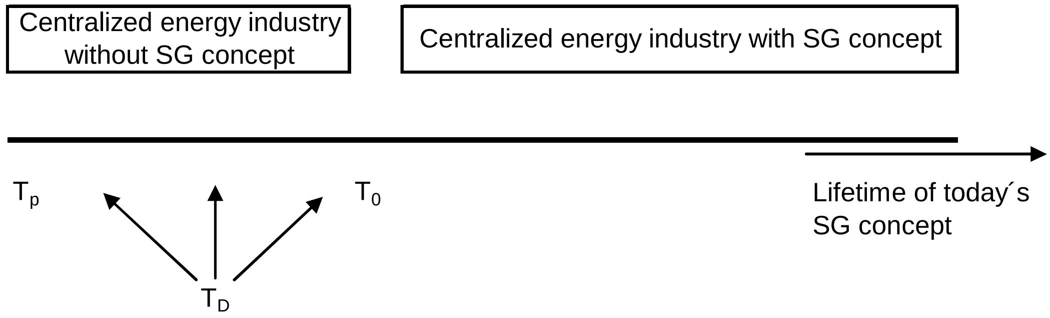

Fig 20. *Various time points during SG implementation*

6.5 Motivation/Stimulation

The chapter 6.4 describes costs and benefits of future SG implementation. In analogy to systematic approach according chapter 4 it represents description of inputs and outputs from EIS and AMI. According to chapter 3.1 the interests could differ for each market participant. Therefore the motivation for each market participant will differ, and methodology described in chapter 5.1 would be applicable.

6.5.1 Market Stimulation Incentives

Trader has to be involved into the practical operation of SG. Only trader could be the real actuating unit that will enable the market stimulation process who would motivate customers to adapt their behaviour in the way to grid stability establishment under decentralized SG concept regarding possible cases described in chapter 6.3.

The price of electricity, which is set from the side of trader to the customer, will represent the final crucial point for SG effectiveness (chapter 6.4). Such smart tariffs (chapter 6.7) would therefore represent real motivation incentive. On the other hand its potential shall be evaluated (chapter 6.7.5)[30].

6.5.1.1 Particular Example

The hybrid vehicles can be mentioned as an example for the market motivation. Question for the customer is: “When is it convenient to buy a hybrid vehicle”. The correct answer is very clear. The economic benefit of the hybrid vehicle (savings of the fuel) must exceed the investment into this technology according to the equation (41). Very similar formula would be valid for each ST implemented under free market conditions using global formula (21).

[30] The price and amount of electricity, available on the market, depends on fact which kind of resource will be during peak hours the marginal one. If it is a plant with high operation costs (e.g. CCGT unit) the price would be high and every saving will be important stimulus for SG effectiveness. On the other hand marginal plant with low operation costs causes very low stimulus.

According to the mentioned example it must be underlined that economic benefits of SG for market participants differ. Benefit for one market participant can cause additional cost for another one. These two facts are therefore antagonistic but according to market rules a positive aspect of more optimal capital allocation should prevail. The global economic benefit (sum of all market participants) can therefore not be so easily evaluated.

6.5.2 Regulatory Stimulation Incentives

Regulatory stimulation can be e.g. obligation to customers to install AMM system. The purchase costs can be spent by distribution system operators but it will definitely be paid from budget that is collected from all electricity customers. Such repayment would be guaranteed by state.

Customers should be afterwards indemnified by the fact that AMM/AMI will enable savings in annual electricity costs regarding to new smart tariffs. It means in other words that the AMI must have its economic purpose according chapter 6.5.3.

6.5.3 Valuation of Particular Costs and Benefits

This thesis has described the systematic approach to SG implementation problem and has mentioned a few instruments for suitable financing methods as well as cost benefit analysis in chapter 6.4.

The systematic approach identifies necessary inputs, outputs and aspects of the system environment and feedback aspects. Such description will be necessary for the cost benefit analysis which should be according to my opinion the most important criterion for valuation if SG could be effective concept or not. The very first and easy approach for cost benefit analysis employs methodology described in chapter 5.1.2 and 4.2.5.3 from the consumer's point of view utilizing time axis in Fig 20.

$$\sum_{t=T_P}^{T} \frac{I_t}{(1+d)^{t-T_D}} + \sum_{t=T_O}^{T} \frac{C_t}{(1+d)^{t-T_D}} = \sum_{t=T_O}^{T} \frac{B_t}{(1+d)^{t-T_D}} , \tag{44}$$

where I_t is particular kind of investment cost (chapter 6.4.1), C_t is particular kind of operational cost (chapter 6.4.2), B_t represents particular benefit (chapter 6.4.3 and 6.4.4), d represents discount, T is lifetime of SG infrastructure, T_P represents beginning of pre-operation investment period ("Manufacturing" period in Fig 5 in chapter 3.5.1), T_O is date of start of commercial operation and T_D date to which discounting is performed.

This approach represents one possible way for SG effectiveness evaluation. The variables in (42) are defined by inputs, outputs and also feedback (chapter 6.4) of the system approach proposed in chapter 4. The most important problem remains data mining for equation (42) which is caused by bed legislation allowing market participants to fog their operating data as a trade secret.

6.5.4 Case Study

For above mentioned experimental approach (chapter 6.5.3) we have chosen common household house (with approx. 10 flats) in the Czech Republic. The case study reflects conditions (e.g. electricity prices, consumption, PV production etc.) in the Czech Republic. This case study would suppose smart usage of electricity accumulation, which is one of most visible benefit (chapter 6.4.3 item B_{acc}).

6.5.4.1 Case Study Presumptions

It is supposed the household house with common consumption of electricity without smart cogeneration (decentralized combined heat and power unit). Additionally it is supposed two ways of smart behaviour of such household.

The main issue regarding smart-grid system based on implementation of PV plant and accumulation is to correctly evaluate expectations of future development of electricity prices. The key driver is the development of spreads between the off-peak load, peak load and the real value of electricity PV plant production diagram, yearly based (considering 41€ in case study). The PV production in 1st and 4th quarter [44] is 40% of production in 2nd and 3rd quarter. Consumption of house is 170kWh in (1st, 4th quarter) 204kWh (2nd and 3rd quarter). Prices of electricity (smart tariffs) are presumed as follows: Baseload (0-24) 57 EUR/MWh, Peakload (8-20) 64 EUR/MWh Offpeak (0-8 and 20-24) 50 EUR/MWh. Finally the battery indicative price is 150 EUR/kWh.

Following tables represent the evaluation of economic benefits divided to two periods, summer characterized by evaluation of peak production of PV plant and winter characterized by higher consumption and lower production of electricity.

Table 2. Benefits (summer 2Q and 3Q) per 1 year [51]

Description	Profit €/MWh	Cycles	Profit €/ year
Load levelling (to enable supply for own consumption)+crowding out of peak consumption	23	4000(180 per year)	623,98
Timeshifting of produced electricity from PV plant	9		77,65
Off-peak timeshifting	14		22,68

Table 3. Benefits (winter 1Q and 4Q) per 1 year [51]

Description	Profit €/MWh	Cycles	Profit €/ year
Load leveling(to enable supply for own consumption)+crowding out of peak consumption	23	4000(180 per year)	249,59
Timeshifting of produced electricity from PV plant	Not available due to higher consumption(load) than PV plant production		
Off-peak timeshifting	14	4000(180 per year)	120,96

Following table shows us result of valuation of the SG system using equation (42) with the implemented smart-metering and accumulation. The calculation used discount rate of 8% due to non-extremely risk connected with the investing to the accumulation and devices responsible for smart behaving of the unit. The negative result of net present value indicates a non-effective solution of an investment. However, calculation mentioned above is based on cash flow of benefits from spreads between off-peak load and peakload and the crowding out effect considering power production from the PV plant.

There were taken into account 3 main benefits constituting B_{acc} from chapter 6.4.3. The benefits were calculated using valuation system xenergy.

- Load levelling effect is based on the feature of battery to hold the consumption as a reliable source of electricity. This effect leads to the crowding out of consuming peakload electricity consumed with the electricity produced in the PV plant.
- Timeshifting effect is based on the accumulating surplus power during peak of the PV plant production (the excess of PV plant production above the consumption) and supporting the delivery of electricity accumulated during the decrease of the PV plant production below level of consumption.
- Off-peak timeshifting effect is marginal activity based on accumulating of off-peak load and shifting this energy to peakload hours. Due to conservative approach this effect was only marginally considered.

Table 4. Total economic analysis [51]

NPV for 20 y lifetime		Category	Result [EUR]
Anuity	9,81815	Income 1Y	1 094,85
Lifetime	20	Outlay year 0 (investment)	11 664,00
Discount	8 %	NPV	- 914,57

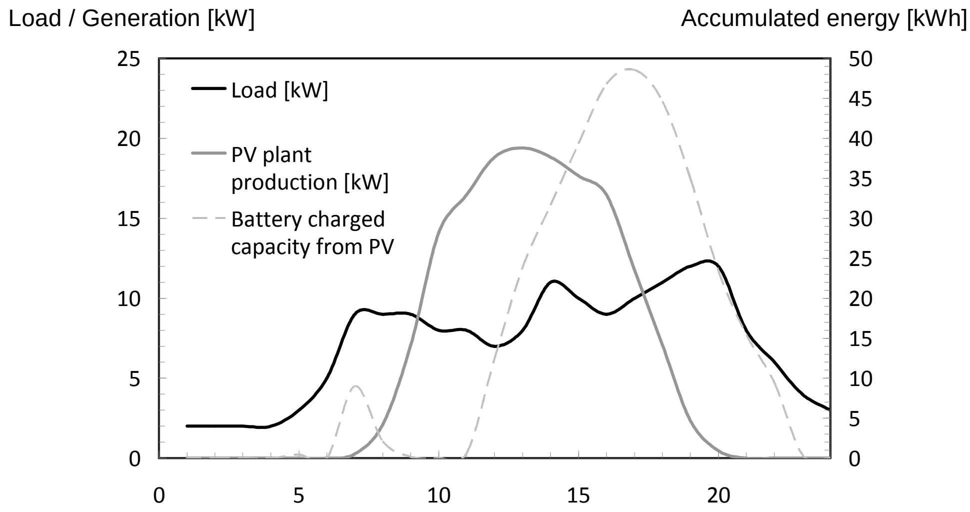

Fig 21. *Battery charging during 2nd and 3rd quarter utilizing PV [51].*

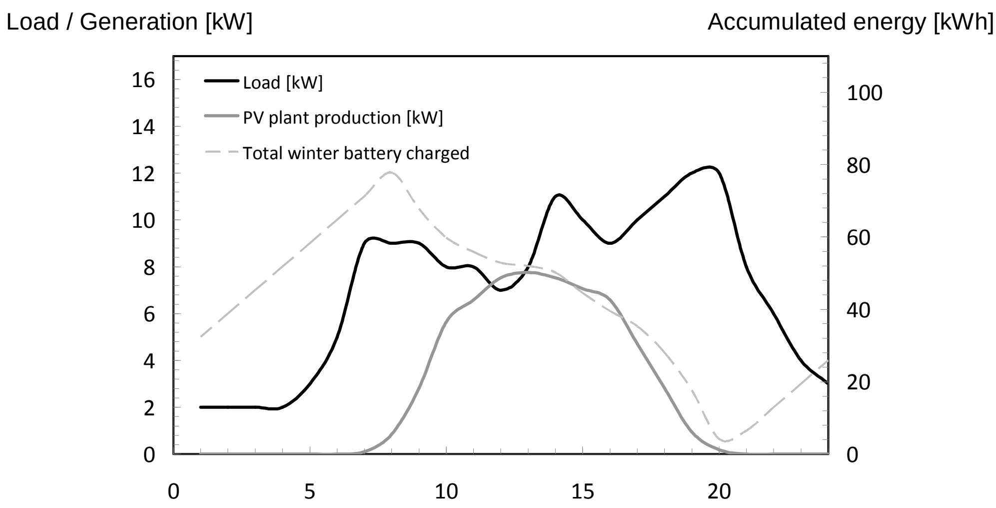

Fig 22. *Battery charging during 1st and 4th quarter utilizing both PV and off peak charging [51]*

The first peak of battery charged capacity from PV in Fig 21 is caused by fact that before 8 AM it seems to be more convenient to store electricity from PV and spend directly electricity from the grid at the off-peak prices.

6.5.4.2 Case Study Conclusions

It is obvious that necessity of SG implementation will grow with increasing amount of decentralized RES-E. Under this condition the potential for the larger spread between low and high price will be much higher than today. The probability for price incentives for reasonable accumulation would be higher. Low price would occur during maximal generation in RES-E and vice versa. Therefore the times of low and high electricity prices would differ from today's peak and off-peak hours.

6.6 Smart Grids and their Impact on Electric Energy Trading Smart Pricing

The real impact of the above-described implementation of the SG on the current energy industry, described by cost analysis (CBA) (chapter 6.4) and economic effectiveness calculation (chapter 6.5.3), is large and unfortunately little cited in open resources. In this thesis author therefore tries to formulate the usable smart tariffs in the way of economical effectiveness and social welfare enlargement after AMI concept implementation.

6.6.1 Electricity Trading

A current trader having in its portfolio electricity consumers must constantly cover their consumption curves. In the case of increasing installations of renewable resources on the side of the consumer (so-called "behind meter"), this curve is, along with its trade obligations/liabilities to the market, burdened with more uncertainty. In most cases the electricity to cover the consumption is provided by long-term contracts within the managed portfolio, to eliminate possible market risk of open positions and is optimized from the perspective of volumetric risk, which complies with results of [15]. The variable (called "residual") part of the diagram creates a short-time position on the organized spot market. This, however, resolved trade commitments in the time span that precedes the moment of delivery by more than 24 hours. Due to the aforementioned uncertainties, there is a change in the coverage of consumption that will result in deviation on the trader's side.

Physically this deviation is currently being dealt with by activating of ancillary services by the TSO. It is obvious that physical criterion can differ from trading one. For social welfare and customer economical effectiveness the trading criterion prevails and physical one remains “only” as a physical border for economical optimization.

The possible lack of transportation capacity and other constraints would cause high volatility in prices in the settlement of deviations and ultimately can lead to considerable market risk for trader.

If we consistently continue to keep the current model which provides management and settlement of deviations from one central location and the same price for all customers in the electricity grid, we will not be able to use all the possible synergies resulting from SG and AMM/AMI. AMM offers trader the information about the status of the decentralized parts of the grid in real time and the trader can reciprocally provide AMI with the information about the immediate local price of electricity (see Fig 23). Such a price - the Smart Local Price (SLP) - can then be a criterion for the demand management of end customers. Therefore this price of electricity, or more precisely the method of its construction, appears to be the fatal factor to the continuation of the SG concept.

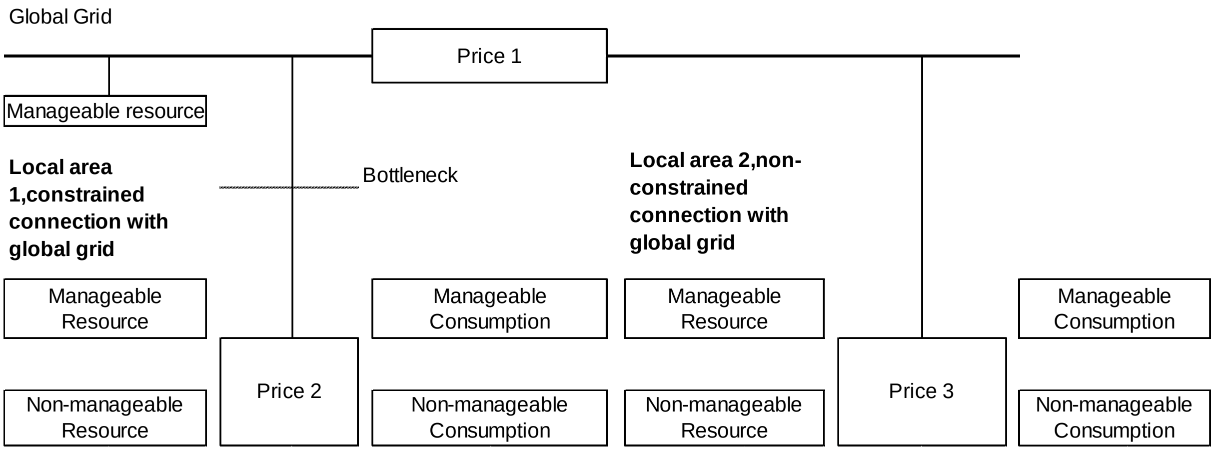

Fig 23. *Prices decouple to nodal prices.*

To determine such SLP, it will be needed to create a Local Balancing Market (LBM) parallel to current global market. This market will associate more consumers, decentralized RES-E generators, accumulators or CHP and last but not least more traders in such a way which would allow a determination of optimal SLP. Existence of more available traders in local balancing market is important to establish compliance with generally accepted doctrine of liberalization and market management Third Party Access Platform (TPA). Optimized SLP will be crucial for the future economic efficiency of the whole concept from the perspective of end customers. The rate of future savings for the customers must exceed the current expenditure for research, development & deployment (RD & D).

Regarding to CBA described in chapter 6.4 this chapter deals with $B_{\text{RES-E}}$, B_{REG} and mainly B_{Market}.

6.6.2 Local Electricity Prices

The reason for necessity of the Local Electricity Prices (LEP) system to spread today's global (zonal) price system (which suppose the constant price in larger region, e.g. Central Europe or the Czech Republic) The LEP are caused by bottlenecks in grids as presented in chapters 6.3.1 - 6.3.4. These bottlenecks cause differences in the electricity price in Europe. The market part (chapter 3.1.1) of (LEP) would be determined on the local balancing market and would be determined by the instantaneous balance of production and consumption in the local network.

We can therefore assume that the regulated part of the price would remain for our analysis the same[31] in order to maintain equal access for all customers. Production of electricity from neighbouring parts of network can influence some particular area only in limited way. These aspects must therefore be implicitly included in the design of future smart tariffs. They will vary in different localities and a price map will always correspond to the immediate state of the network. The success of prices predictability is therefore given inter alia by the success of the local weather forecast.

The above described fact would give rise to so called price nodality (SLP is in the same time nodal price) provided that the transmission capacity of grids is limited. Prices for the entire customer portfolio would in the SG therefore strongly differ. SLP will not only be influenced by generation but also by the response of local customers. Predictability of price development would be made possible thanks to the accurate mapping of both - consumer portfolios and also all decentralized sources. The local nature of the pricing of electricity also causes the traders portfolio to diversify. Individual sub-portfolios will be managed independently from other local portfolios. If there is a significant price increase in other local areas, (price 3 on Fig 23), surplus areas with a lower price 2 may be unable to deliver electricity to the deficit area due to mentioned restrictions (bottlenecks in the grid). Therefore, there is no unification of prices and local prices 3 are therefore increased. The market impacts are described in chapters 6.3.1 - 6.3.4.

6.6.3 Specific Intelligent Tariffs and Their Use in the Home

Tariffs together with the AMM system, which is capable of two-way communication, can motivate the time shifting of consumption of certain appliances according to the needs of traders. Such management is possible for those appliances that do not depend on the presence of the user. The mentioned demand response will have following impacts on the trader. Traders will be motivated to implement a system that would work flexibly with the price for end customers. Such a system will need to communicate with smart metering in place of consumption, which provides the trading system inter alia with the information about the connected appliances switched over to the stand-by mode waiting for a lower price. This feedback will provide the trader with response of its customer's portfolio on the change of the electricity price.

6.6.4 Smart Tariff Construction and Requirements on Smart Price

To reflect above mentioned aspects especially those described in chapters 6.1-6.5 of Smart Grid, the structure of price must be changed massively. Some brand

[31] It is of course not closed discussion and local grid conditions can cause different regulated part of each payment. Such problems should be solved in following research.

new concept of electricity pricing must be formulated to this end. Moreover smart tariffs based on SLC (chapter 6.6.1) represents motivation (according chapter 5.3) for customer and are mean for demand side management. Time variability of price motivate to time shifting of demand and utilizes local grid conditions in the way described in chapters 6.3.1 - 6.3.4.

The real impact of smart prices depends on SLP differences during daily time (volatility) as well as volume of consumption possible to manage (shift). This value depends on appliances used by end consumers (household as well as industrial). List of such appliances by household customers is presented on Table 5. To utilize the management some price level for some particular appliance (value of consumption) must be set. The aggregate information of price levels and switched demands sets feedback of whole system (chapter 4.2.5) on any price change.

Table 5. Household appliances according to their manageability

Consumption type	**Manageable**	**Group**	**Description**	**Appliances**
Accumulative consumption	Yes	Group A	electrical energy is transformed into another form of energy	water heater, freezer, fridge, fridge freezer, laptop, mobile phone charger, air conditioning*
Consumption with accumulative utility	Yes with *a priori* time nomination	Group B	electrical energy is transformed into utility that can be stored or shifted	washing machine, dishwasher, clothes dryer, chargers
Consumption with real time utility	No	Group C	electrical energy is transformed into utility that can not be stored or shifted	lighting, TV, set-top-box, CD/DVD, iron, jug kettle, microwave oven, electric cooker, PC with peripheries, vacuum cleaner
Heating*	Yes	Group D	electrical energy is transformed into thermal energy accumulative in thermal capacitor	solid or liquid thermal accumulator
Accumulator charge in PHEV/PEV	Yes when PHEV/PEV is parked	Group E1	electrical energy is directly accumulated into accumulator in PHEV/PEV	plug-in (hybrid) electric vehicle
Accumulator charged in the house (not in PHEV/PEV)	Yes	Group E2	electrical energy is directly accumulated into accumulator that can be replaced with accumulator in PHEV/PEV	accumulator can be replaceable with PHEV/PEV
Stand by regimes	Yes/No	Group F	Vast majority of household appliances are in stand-by regime with consumption most of the time useless. The consumption can be minimized by smart management in smart – ready appliances but their (not stand-by) operation can not be managed similarly to group C	

PHEV – Plug - in Hybrid Electric Vehicle

PEV – Plug -in Electric Vehicle

* today's used appliance can be replaced by accumulative one.

6.7 Smart Tariff Formulation

As it is written above the smart tariff will have to motivate the customer on the one hand for energy (and capital) savings in the way of SWF maximization (chapter 5.1 and 5.3 herein) and on the other hand to shift the consumption in the way of grid stability establishment (chapter 6.3 herein).

According to author's opinion smart tariff will be based on combination of two basis, availability and price intraday development. Availability is based on possibility of appliance demand response. In most cases, the appliances can be in general divided into groups as it is described in Table 5. Manageable consumption represents value of possible ancillary services (negative regulative energy) as well as potential of customer savings. Structure of price changes represents motivation for customer demand response as well as value of customer financial savings as per chapter 5.

6.7.1 Availability

The consumption can be seen as vector set by its coordinates.

$$Vector:(coordinate_1, coordinate_2, coordinate_3, ...) \tag{45}$$

Especially vector of availability can be expressed

$$\vec{V}_A:(L(t)_A, L(t)_B, L(t)_C, L(t)_D, L(t)_E) \tag{46}$$

Each coordinate represents value of consumption of particular group of appliances. Such groups of consumption differ because of its availability and manageability (Table 5). Therefore its valuation differs as well.

6.7.1.1 Group A – Accumulative Consumption

This group of appliances allows real time manageability with guarantee of some minimal sum of consumption each day.

Real value of described manageable parameters depends on management carried out by communication between AMM devices. Coordination between AMI devices shall be carried out using some kind of trading system (AMI communication platform[32]) as per of above described preference of trading criterion during AMM. The real time changing of parameters *p* represents mean for real demand response. Should demand response does not influence behaviour of customer, the L_A remains constant in following equations.

[32] Description of such AMI platform exceeds framework of this thesis.

$$L(t)_A = k(t)_{t\,h} \cdot k(t)_{t\,a} \cdot l(t)_A$$
$$C_A = \int_0^{24} L(t)_A \, dt = const. \quad , \qquad (47)$$

where $k(t)_{t\ h}$ is manageable parameter of simultaneousness between households (or industrial customers), $k(t)_{t\,a}$ is manageable parameter of simultaneousness between appliances, $l(t)_A$ is load of appliances from group A in some local area, $L(t)_A$ is total load of appliances from group A in some local area in the time *t* and C_A is total daily consumption of group A in local area.

6.7.1.2 Group B – Consumption with Accumulative Utility

This group of appliances allows manageability with some nomination because beginning of consumption and enough time for operation must be guaranteed.

$$L(t)_B = k(t)_{t\,h} \cdot k(t)_{t\,a} \cdot l(t)_B$$
$$C_B = \int_0^{24} L(t)_B \, dt = const. \quad , \qquad (48)$$

where l_B (*t*) is load of appliances from group B in some local area, $L(t)_B$ is total load of appliances from group B in some local area in the time *t* and C_B is total daily consumption of group B in local area. in the time *t*.

6.7.1.3 Group C – Consumption with Real Time Utility

This group of appliances allows no possibility of demand response, independent on customer behaviour. Therefore no manageable coefficients *k* similar to those provided in the other chapters of 6.7.1 exist.

6.7.1.4 Group D – heating

This group is similar as group A. The difference is that $k_{t\,a}$ in equation (49) mostly equals 1 because there is mostly one heating system in household. In case of more households the $k_{t\ h}$ shall be managed by coordination between AMI and its coordination system (AMI communication platform).

$$L(t)_D = k(t)_{t\,h} \cdot k(t)_{t\,a} \cdot l(t)_D$$
$$C_D = \int_0^{24} L(t)_D \, dt = const. \qquad (49)$$

where l_D (*t*) is load of appliances from group D in some local area, $L(t)_D$ is total load of appliances from group D in some local area in the time *t* and C_D is total daily consumption of group D in local area. in the time *t*.

Difference of Group D from Group A is in spread of electric heating. Lots of customers use not electrical heating system.

6.7.1.5 Group E – Accumulator in PHEV/PEV or charged in the Household

To eliminate high coefficient of simultaneousness of parked PHEV/PEV charging, additional accumulator can be placed in the house. Accumulator in PHEV/PEV can be than replaced or quickly charged by accumulator in the house. Group E1 therefore represents parked PHEV/PEV charging and Group E2 represents house accumulator charging.

$$L(t)_{E1} = k(t)_{th} \cdot l(t)_{E1}$$
$$L(t)_{E2} = k(t)_{th} \cdot l(t)_{E2} \qquad (50)$$
$$C_E = \int_0^{24} L(t)_{E1} + L(t)_{E2} dt = const.$$

where $l(t)_{E1}$ is load of parked PHEV/PEV charging and $l(t)_{E2}$ is load of house accumulator in some nodal area in the time *t*.

House accumulator has less priority of charging than accumulators in parked PHEV/PEV.

6.7.2 Price

The price can be seen as vector set by it's coordinates as well as availability.

$$Vector : (coordinate_1, coordinate_2, coordinate_3, ...) \qquad (51)$$

Especially vector of price can be expressed

$$\vec{V}_P : (P(t)_A, P(t)_B, P(t)_C, P(t)_D, P(t)_E), \qquad (52)$$

where P_A – P_E represents prices for appliances from groups A – E.

Each coordinate represents price for particular group of appliances. Each coordinate is time-variable in the same time.

6.7.2.1 Regulated Part of Price

As per chapter 3.1.2 regulated segment prices[33] are set by regulative authority. According to nodal prices and local areas methodology as it is written in chapters 6.3 6.6 the consumption is managed by real time price changes. There are two possibilities:

- Regulated part of price as a part of SLP can differ according local grid conditions between various local prices.
- Regulated part of price as a part of SLP can be the same in all local areas.

[33] Particular prices are provided in chapter 3.2 in Table 1.

Applicability of above mentioned possibilities depends on used legislations. Both are possible. Its valuation exceeds framework of this thesis.

6.7.2.2 Liberalized Part of Price

Liberalized price alternation shall establish real motivation for market participants with securing of price signals. Its alternation, in contrast with regulated part of price, is necessary. Therefore following analysis (chapter 6.7.3) does not distinguish the parts of electricity price. It is taking into account the whole smart electricity price for tariff optimization.

6.7.3 Motivation for Customer

In chapters 5.3.1 and 5.3.2 the methodology for motivation is described. The savings obviously represents massive motivation for all market participants. According to chapters 6.7.1 and 6.7.2 the minimisation of total electricity costs for each time can be expressed as follows.

$$\vec{V}(t)_A \cdot \vec{V}(t)_P \rightarrow MIN \tag{53}$$

Customer cannot set some exact price level for each group of appliances. Customer is motivated by minimization of total payment. The optimization process can be successful under condition, that price corresponds to real flow-based electricity balance in the nodal area[34]. After unbundling process interests, behaviour (and whole decision process) of traders can deviate from interests, behaviour (and whole decision process) of DSO. There is no flow based trading system so far.

6.7.4 Evaluation of Potential for Savings

The potential for savings is set by total capacity of manageable appliances. For real potential evaluation, the data from real appliances operation is needed. To this end statistical data from the REMODECE project data was used [52].

It is important to emphasize that analysis is based on author´s presumption about manageability of usage of particular groups of appliances. Appliances are divided according to the usability of today´s appliances. Some possible future change in principles of these appliances can of course influence mentioned appliance´s usability.

[34] It is similar to flow based allocation method in case of cross-border capacity allocation, discussed in [54].

Table 6. Maximal daily consumption according appliances [52], [53].

			Total Daily Consumption	
			Work Day	Weekend Day
	Daily maximal capacity	**W**	3 651	3 554
A	Accumulative	W	923	760
	Water heater	W	621,0	411,0
	Freezer	W	64,0	57,8
	Fridge	W	39,0	38,1
	Fridge freezer	W	52,0	52,3
	Air - conditioning	W	355,0	287,0
				0
B	Non accumulative	W	144	159
	Washing machine	W	44,5	52,2
	Dishwasher	W	48,2	51,8
	Clothes dryer	W	63,6	98,0
C	Non shiftable appliances	W	471	464
	Lighting secondary room	W	7,3	6,0
	Lighting living room	W	15,6	12,8
	TV Plasma	W	131,5	108,4
	TV LCD	W	62,2	58,0
	TV CRT	W	30,0	28,1
	TV settopbox	W	11,2	10,6
	HIFI and radio	W	5,8	5,9
	CD/DVD recorder	W	3,3	3,2
	Others*	W	65	60
	Jug kettle	W	16	17
	Microwave owen	W	6	7
	Electric cooker	W	79	114
	Desktop PC with monitor	W	51	51
	Laptop	W	13	12
	Router	W	6	7
	Printer	W	4	4
	Wireless local area nwtwork	W	8	7
	Vacuum cleaner	W	19	36
	Mobil phone charger	W	1	1
D	Central heating - Accumulative	W	1 543	1 543
E	PHEV	W	375	375
	PHEV (off peak, night)**	W	750	750
F	Standby***	W	0,0	0,0

*5% of other comsumption
**charging of PHEV during off-peak hours is taken into account
***Standby represents cca 7% of consumption of respective appliances. It is already contained in particular consumption of appliances

Table 7. Total daily consumption according appliances [52], [53], [55].

		Total Daily Consumption		Ownership	Corrected Total Daily Consumption		Corrected Percentage Daily Consumption	
		Work Day	Weekend Day		Work Day	Weekend Day	Work Day	Weekend Day
Total consumption	**Wh**	70 658	69 240	14,3%	10 076	9 834	99%	99%
A Accumulative	Wh	16 840	14 769	27,0%	4 546	4 085	45%	42%
							0%	0%
Water heater	Wh	7 716,0	6 251,0	25,0%	1 929,0	1 562,8	19%	16%
Freezer	Wh	1 505,6	1 307,7	25,0%	376,4	326,9	4%	3%
Fridge	Wh	865,9	843,4	90,0%	779,3	759,1	8%	8%
Fridge freezer	Wh	1 139,6	1 158,2	79,0%	900,3	915,0	9%	9%
Air - conditioning	Wh	5 613,0	5 209,0	10,0%	561,3	520,9	6%	5%
B Non accumulative	Wh	1 884	2 052	54,8%	1 032	986	10%	10%
Washing machine	Wh	576,9	448,1	94,0%	542,2	421,2	5%	4%
Dishwasher	Wh	557,6	595,0	61,0%	340,1	363,0	3%	4%
Clothes dryer	Wh	749,2	1 009,0	20,0%	149,8	201,8	1%	2%
							0%	0%
C Non shiftable appliances	Wh	5 897	6 382	59,2%	3 492	3 758	35%	38%
							0%	0%
Lighting secondary room	Wh	68,8	59,1	100,0%	68,8	59,1	1%	1%
Lighting living room	Wh	106,5	103,3	100,0%	106,5	103,3	1%	1%
TV Plasma	Wh	1 051,4	1 150,5	15,0%	157,7	172,6	2%	2%
TV LCD	Wh	507,0	600,8	40,0%	202,8	240,3	2%	2%
TV CRT	Wh	347,2	364,7	38,0%	131,9	138,6	1%	1%
TV settopbox	Wh	215,5	216,8	33,0%	71,1	71,5	1%	1%
HIFI and radio	Wh	122,3	123,9	72,0%	88,1	89,2	1%	1%
CD/DVD recorder	Wh	61,1	63,2	67,0%	41,0	42,4	0%	0%
Others*	Wh	1 172	1 105	100,0%	1 172	1 105	12%	11%
Jug kettle	Wh	163	165	50,0%	81	83	1%	1%
Microwave owen	Wh	69	73	67,0%	46	49	0%	0%
Electric cooker	Wh	563	862	80,0%	450	690	4%	7%
Desktop PC with monitor	Wh	720	718	59,0%	425	424	4%	4%
Laptop	Wh	158	160	47,0%	74	75	1%	1%
Router	Wh	122	131	48,0%	59	63	1%	1%
Printer	Wh	88	88	67,0%	59	59	1%	1%
Wireless local area nwtwork	Wh	157	154	33,0%	52	51	1%	1%
Vacuum cleaner	Wh	185	220	100,0%	185	220	2%	2%
Mobil phone charger	Wh	21	23	100,0%	21	23	0%	0%
D Central heating - Accumulative	Wh	1 543	1 543	6,8%	105	105		
E PHEV (off peak, night)**	Wh	9 000	9 000	10,0%	900	900	9%	9%
F Standby***	Wh	9,3	9,3					

*5% of other comsumption
**charging of PHEV during off-peak hours is taken into account
***Standby represents cca 7% of consumption of respective appliances. It is already contained in particular consumption of appliances
Cenatral Heating Qwnership according to ČSÚ data

Table 8. Total household yearly consumption [52], [53].

Total Household Consumption	**Unit**	**Total**
REMODECE data	kWh	3 614
PRE data*	kWh	2 643

*PRE data counts with presumption that no electricity heating is employed

Using above provided data the overall potential of SG implementation can be evaluated regarding benefit B_{Market} as per Chapter 6.4.3 herein. This benefit originates in demand response and is set by related availability (Chapter 6.7.1) and price vector (Chapter 6.7.2).

The provided data represents common appliances consumption course of single household. In Table 7 the correction by ownership percentage is made. For more households the ownership percentage represents coefficient how to evaluate data for local area of some households. Because of uncertainty of market price which is set by market equilibrium, only the parametric potential of benefit B_{Market} can be evaluated.

The evaluation and comparison of particular appliances by single household and average household in the winter and summer time is provided in Supplement B.

6.7.5 Real Potential Valuation

As it is shown on figures in Supplement B the potential for savings changes related to daily hour and calendar month. The largest potential is during winter time because of accumulative heating potential.

By single household the shift able maximal capacity of appliances is set by observed data from REMODECE project. The average household applicable for some local area depends on ownership as per Table 7.

Total potential course in local area is provided in Table 16 in Supplement B and shown on Fig 24 - Fig 26 below. The potential of consumption shifting differs not only during day but also during the year. The fact that there is no massive difference between summer and winter time is caused by low percentage of ownership of accumulative heating by the common households (Table 7).

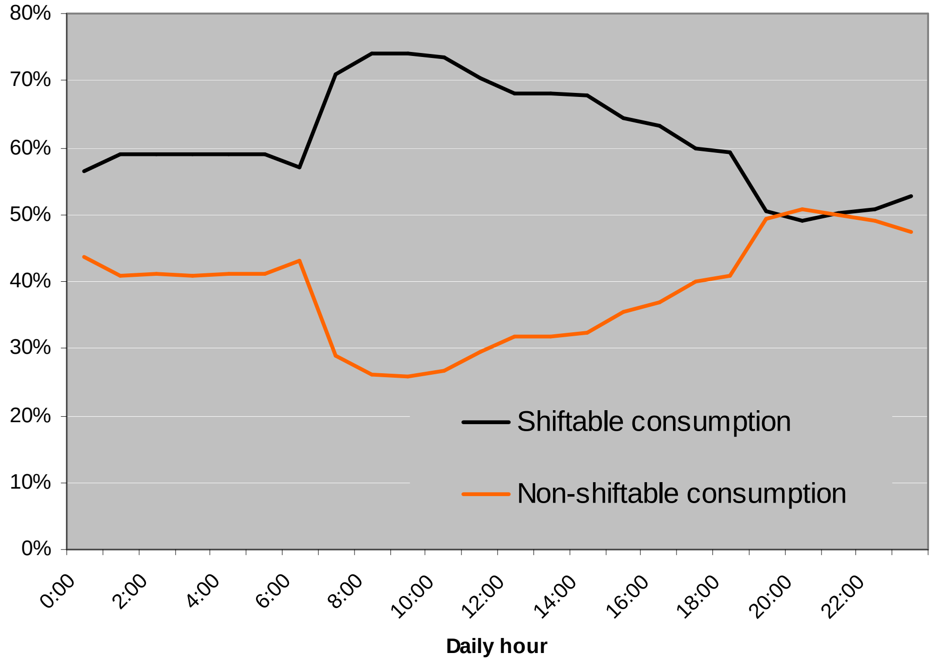

Fig 24. *Shiftable potential (April-September)*

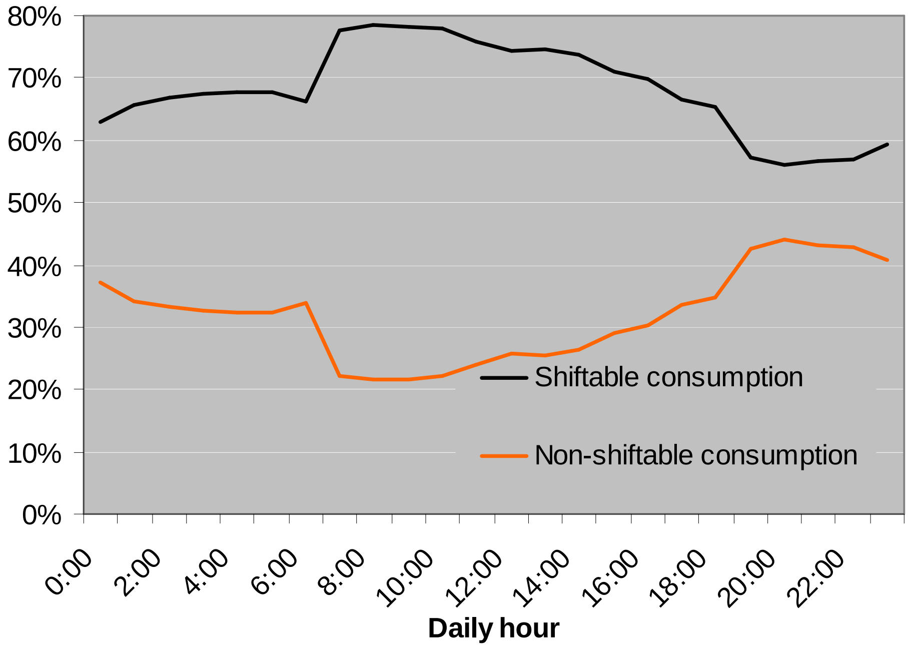

Fig 25. *Shiftable potential (October-March)*

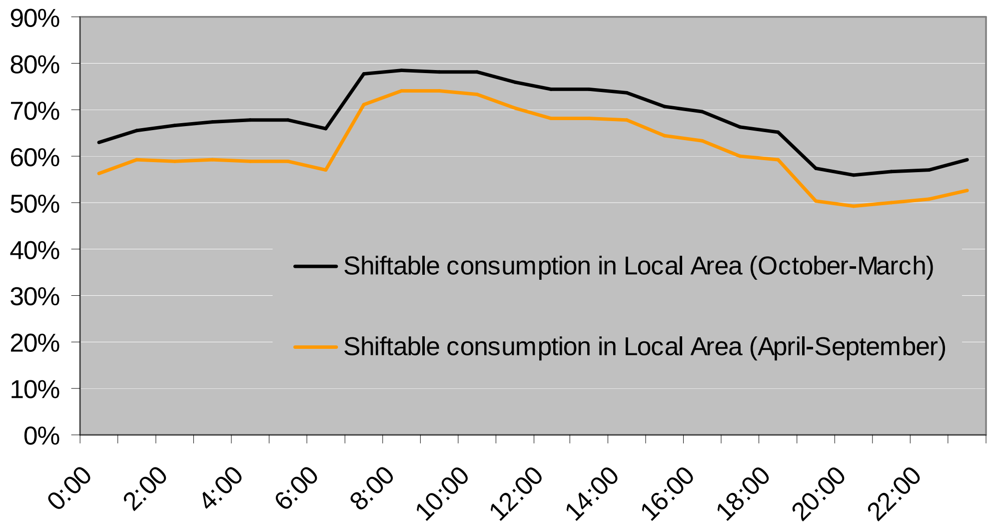

Fig 26. *Shiftable potential*

The potential of consumption shifting in the way of B_{Market} (as per Chapter 6.4.3.) maximization behaves as it is shown on Fig 26. The B_{Market} can be set parametrically. The calculated average potential is in the winter 68% and during summer 61%. Conservative presumption of shiftable portion can be set as 60% of consumption. The equations (36), (37) can be according to provided analysis parametrically changed into following forms.

$$B_{market} = \sum_{t=T_0}^{T} \frac{0{,}6 \cdot C(h)_h \cdot \sum_{h=0}^{8760} \left[p(h)_{e\_peak\ h} - p(h)_{e\_offpeak\ h} \right]}{(1+d)^{t-T_D}}, \tag{54}$$

where $C(h)_h$ represents total consumption in some local area, $p(h)_{e\_peak}$ is electricity price during peak hours ("high smart price") in the hour *h*, $p(h)_{e\_offpeak}$ is electricity price during off-peak hours ("low smart price") in the hour *h*, B_{market} represents total benefit resulting from demand side management and $B(t)_{market\ t}$ is benefit of demand side management in the year *t* (time variable).

6.7.6 Dimensioning of conductors in local areas

The grid management is critically set by local-grid conductor dimensioning. The critical criterion is value of electrical current. The electrical current sets at the same time value of energy and also value of thermal strain of conductors. According to methodology used for conductor dimensioning [47] Czech distribution companies use special coefficients for conductor dimensioning. Such coefficients originate in fact that the consumption times of vast majority of appliances differs. Therefore it is not necessary to calculate capacity of conductors to sum of installed capacity (maximal electrical current) of all appliances. Therefore the maximal capacity/current for that the conductors are dimensioned is set generally by following equation:

$$L_{Tm} = coef \cdot L_m, \tag{55}$$

where L_{Tm} is total load of group of consumer (e.g., village), *coef* is applicable coefficient of simultaneousness and L_m is maximal average household load.

The coefficient c_t is used for estimation of time simultaneousness of consumption in the group of more customers e.g., village. According to [20] the common value of c_t is 0,38 for flats c_{tf} and 0,6 in groups of solitaire buildings c_{th}. Annual consumption of average household in the EU according is in Table 8.

After massive expansion of EV (author's presumption 10% of electric) the situation with conductor capacity would dramatically change. EV charging current would increase the daily consumption of region [56]. Moreover coefficient of simultaneousness would be much higher (according to my research about 0,9 – 0,8 c_{te}) because vast majority of consumers would charge EV during the same times in the place where they live or work.

6.7.6.1 Case study results

Author's approach in this viewpoint is to evaluate impact of EV expansion in 1 150 household village in Czech Republic, presumptions 10% penetration of households by EV. Author uses standard methodology according to [20], [47]. Dimensioning of feed conductors is set by maximal total consumption of 1 150 households provided: 40 flat houses (n_f) with 20 flats, 150 double household houses

(n_{dh}) and 50 single household houses (n_{sh}). Maximal consumption of average household is C_m and maximal total load is L_{Tm} set before EV expansion by equation (54) and L_{Tme} after expansion by equation (57).

Table 9. Inputs for case study

Case Study Inputs	Value
Number of falt houses (n_f) with the 20 flats	40
Number of bouble houses (n_{dh})	150
Number of single houses (n_{sh})	50
Number of households in the nodel area (n)	1150
Coefficient of simultaneousness between falts (c_{tf})	0,38
Coefficient of simultaneousness between households (c_{th})	0,6
Coefficient of simultaneousness between electromobiles (c_{te})	0,85

$$L_{Tm} = c_t \cdot L_m = (20 \cdot c_{tf} \cdot n_f \cdot c_{th} + 2 \cdot c_{tf} \cdot n_{dh} \cdot c_{th} + n_{sh} \cdot c_{th}) \cdot L_m \quad (56)$$

$$L_{Tme} = L_{Tm} + c_{te} \cdot (20 \cdot n_f + 2 \cdot n_{dh} + n_{sh}) \cdot L_e\,, \quad (57)$$

where L_m is maximal average household load, L_e is average charging consumption of electric vehicle (both corrected by ownership percentage).

This c_{te} coefficient can be changed by the means of demand side management (DSM) also [57].

Table 10. Dimensioning impact of EV

	Average household	Electro Vehicles Influence
Household Maximal Load [W]	900	8,33%
Household Maximal Electromobility Load [W]	75	
Dimensioning of conductors for 1150 households [kW]	253	29,01%
Dimensioning of conductors 1150 households [kW]	326	

It is shown in Table 10 that influence on total village feed dimensioning is almost 30%. Author’s survey moreover showed that effective DSM (and load shifting) connected with EV would be jeopardized by large fees for reserved capacity applied in distribution systems. Therefore solution only by the means of SG in this would be difficult. Massive DSM would therefore be needed. This fact would i.a. results in incentives for massive decentralized Combined Heat and Power units (micro CHP).

6.7.6.2 Overloading of Conductors Caused by EV

Identified conclusion as described above, also discussed in [58], is therefore risk of conductors overloading. According to author's analysis, apparent risk of congestion provoked by expansion of EV jeopardizes electricity grids because of large coefficient of simultaneousness of EV charging. The AMI devices with SG concept implementation would again help with such phenomenon as shown in chapter 6.2.

To support cure against local conductors overloading the massive installation of micro-CHP is probable. Therefore not only implementation of AMI can be predicted together with potential EV boom. Micro-CHP is a specific form of CHP with low performance designed mainly for individual households. As a replacement of a standard domestic gas boiler, it generates power for consumption in the home or for selling it with the feed–in tariff. In dependence of natural gas and electricity prices such concept in connection with smart tariffs application is on the edge of economical effectiveness according to net present value (NPV) method or real-option approach. But increasing cost of power transport (contained in regulated part of price according chapter 3.2) due to higher capacity needs of e.g. EV would cause increment of retail electricity price. This fact could afterwards result in the higher economic purpose of these micro-CHP devices and in their massive implementation.

6.7.6.3 PHEV Storage Possibility

It is necessary to contribute that implementation of PHEV brings one important aspect. Potential of electricity accumulation utilization (benefit B_{acc} chapter 6.4.3) is supported by PHEV as well as B_{MOB} according chapter 6.4.4.

6.8 Data Energy Coupling and Datapooling

AMM/AMI infrastructure will require transports of large amount of data to provide necessary information for market participants. This fact does not have base in today´s legislation because lots of such data represent today often confidential information. Consumption of some particular consumer would help competitive trader with price concurrence.

In Datapooling concept the access to data base would have to be managed by independent entity. Moreover if of local third party access concept and local balancing market would be established, the access will have to be in real time and connection of particular trader´s ICT systems with this database will be needed.

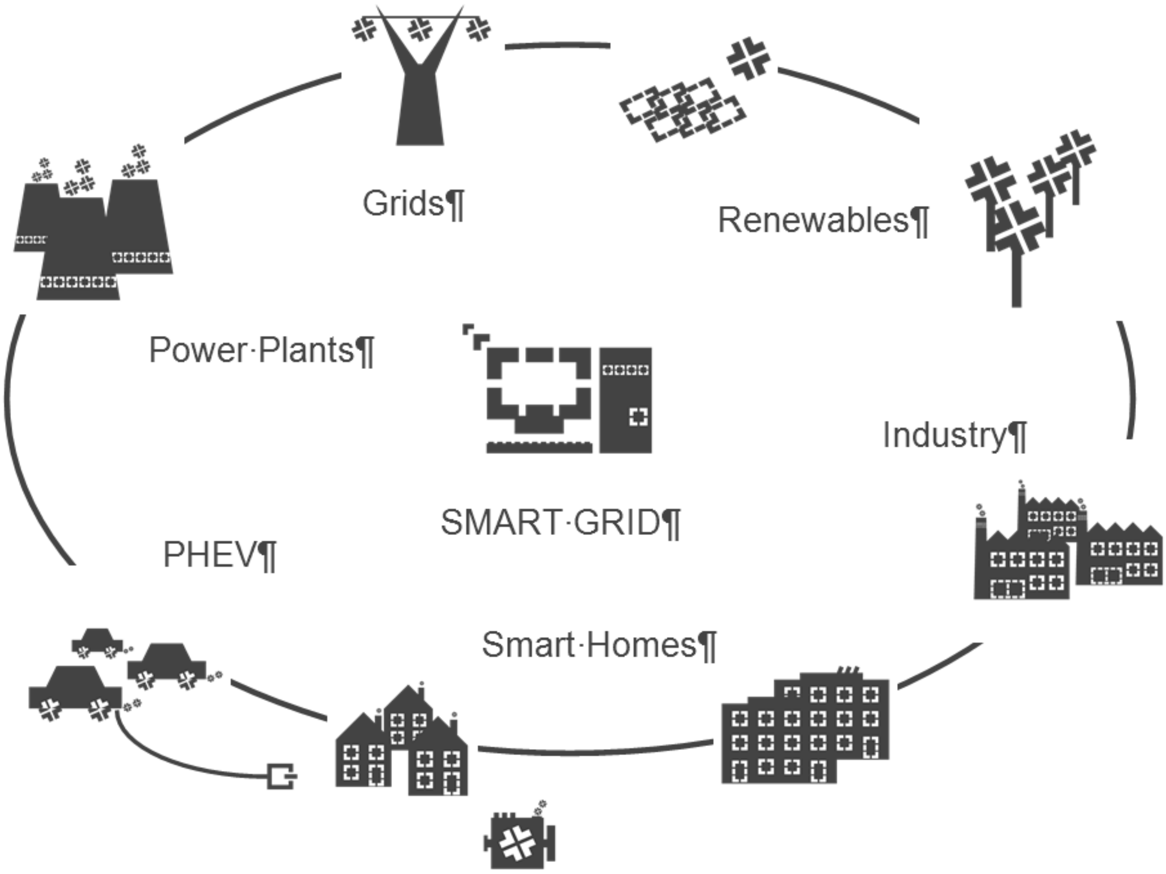

Fig 27. *Infrastructure of market participants according to author in the SG concept*

7 Results

This dissertation thesis describes author´s research based on systematic analysis of energy branch. The infrastructure of market participants as well as applied market model served as theoretical basis. The author describes EIS and related subsystems to find goals of this thesis formulated in chapter 1.1. By the means of deduction process the author applied his systematic approach on a few case studies (chapters 6.2, 6.3, 6.5.4, 6.7.5, 6.7.6). The reached goals were synthetized to the end of testing author´s hypothesis formulated in chapter 1.2. The structured results of author´s thesis follow.

7.1 Goals of this Thesis

The goals of this thesis, according to chapter 1.1, were reached by author´s research and are described below.

7.1.1 Description of Main Aspects of Energy Branch

In chapter 3.1 there is a deep description of main aspects of energy branch from the systematic point of view. Electricity represents the most universal form of energy. Its usability is higher than other forms. The main physical aspect is unstorability of electricity. Therefore there is the necessity of massive investments into the grid stabilization. This fact influenced i.a. regulation of EB and thus infrastructure of market participants.

The main structural aspect is the fact that EB is in fact divided into two parts, liberalized and regulated. This fact influenced price structure as well as relationship between particular market participants[35]. The regulated market participants are directly under the management of regulatory authority and indirectly under the influence of politics. The feedback provided by regulative subsystem is influenced not only by legislation but also by regulatory authority.

The mentioned facts influenced structure of price for consumers massively. The regulation moreover represents the majority of price for consumers. In this regulated segment there is the potential of financial sourcing for any new smart technology. The costs can be transmitted to electricity consumers (or tax payers) in full extend. This fact brings high risk of future costs that would not be balanced by related benefits.

On the other hand implementation of any ST in fully liberalized part of energy branch should subordinate this new technology under market optimization. The risk is connected with the fact that liberalized capital [15] tries to avoid the capital-intensive

[35] In the author´s viewpoint market participants are at the same time elements of the system.

technologies with long construction and life times and prefer capital less intensive investments.

7.1.2 Description of Today´s Theoretic Framework for ST Concept Implementation

In chapter 3.4 the ST in EB are described according to today´s state of the art. As it is written in this chapter, the massive structural change has recently taken place in the EB. They were motivated by two main aspects. The first is liberalization of energy branch, motivated by the EU. The impacts are visible in the described structure of EB as it was described in the first goal. The second aspect is prevailing opinion that global climate change is influenced mostly by human global activities in EB (chapter 3.3). The support of energy produced in RES-E (as a regulation) was applied and it influenced the system of EB massively. As a feedback it influenced market participants not only in regulated part but also in liberalized part of EB, because it results in massive decrease of electricity price on the market (not for customers).

In chapter 3.5 there is described today´s state of the art of financing methods applicable in the EB and especially in sector of ST. The methods based on venture capital or loans financing were mostly utilized in the sector of RES-E. The usability of these methods is based on condition of positive NPV for investor. Investment with uncertain value of NPV needs some subventions from public authority. Analogically other ST would need support mechanism if their NPV is not clearly positive.

The technology learning process (chapter 3.7) describes results of manufacturing capacities enlargement. This description can be seen as afford of systematic analysis because it tries to describe feedback to the system. On the other hand this description does not presume impacts on price of electricity as a final product. It only describes manufacturing costs of power plant technologies.

7.1.3 Formulation of Systematic Description of Energy Branch

In the chapter 4, author utilizes systematic analysis for description of EB system relations. The feedback is identified as a crucial aspect of future system behaviour and possibility of its management. The inputs as well as outputs are described in the chapters 4.2.2, 4.2.3.

Free market optimizes in the real time. Sectors with large inertia (long construction times and tricky sub-contractor chains necessary for construction) cannot be flexible for rapid market changes. The most important fact that author identifies is, that this system has its specific feedback, influencing again the inputs. It was manifested on subsystems of EB in case studies (chapters 6.6, 6.7 and 6.8). As a criterion for system development the social welfare of market participants (expressed as economic effectiveness) was chosen by the author. This criterion motivates market participants for some specific behaviour. This behaviour can influence transformation of inputs in the sub-system which represents at the same time feedback of this sub-system.

Author expresses opinion that appropriate principles of motivation represent instrument applicable for system management. The methods for market participant's motivation are described in chapter 5.1.1. Incentive strategies for system regulation manifesting aspects of the future system development can be provided only by the qualified legislation. Bad legislative regulation can cause on the other hand SWF descent.

Author's presumption is that physical as well as legal persons behave in the way of growing utility and its utility can be measured by the means of NPV criterion. This fact is a crucial point for behaviour of market participants and therefore for description of feedback of the system. The basis of system behaviour originates in behaviour of all entities involved in the system. Qualified regulation connected with motivation provided by appropriate legislation (regarding to described principles of system feedback existence) therefore represents large incentive for all participants. This control can be performed by the strategy of direct system legislative incentive that changes feedback of particular sub-system[36]. It is important to emphasize that any regulation and control should not be retroactive to provide for investors comfortable and predictable environment regarding their *bona fide* (good faith). Vast majority of AMM/AMI costs (chapter 5.1.1.2) would have to be incorporated to establish correct motivation incentive. The choice of appropriate global criterion is crucial for correct incentive methodology. The social welfare (SWF) as global criterion (chapter 5.2.3) for physical persons is the most relevant aspect. Only SWF growth can establish growing future market for the rest of EIS. The main contribution of the author is application of systematic approach on smart grid implementation and cost benefit analysis.

7.1.4 Formulation of Methodology for Smart Grid Impacts Valuation

Utilizing of state of the art theoretic framework of energy branch as well as SG, the author formulated methodology for SG impact valuation. It is presented in chapter 6. As a presumption for valuation methodology, the physical grid infrastructure influenced by future development of distributed intermittent resources as well as growing distributed consumption is described in chapter 6.3..

Future development of SG concept will be reinforced by development of AMI devices, conducted together with growing share of distributed RES-E and PHEV. According to author´s research (documented in case study in chapter 6.7.6) this fact can result in risk of local grid overweighting. The real time measurement of electricity flow will moreover enable nodal structure of electricity price level. The situation is

[36] It is obviously possible to change infrastructure of subjects directly, but this change is structural change.

described in chapters 6.3.1 - 6.3.4. When local consumption of electricity or generation of electricity in intermittent distributed resources grows, the pressure for local transmission conditions of the grid grows as well. The fact of intermittence makes this situation moreover worse. The impacts to demand supply equilibrium are presented in Fig 15 - Fig 18. This important fact has not been described in available literature so far.

The above mentioned findings (previously published by the author in [7] and [38]) were by the author analysed by the means of described systematic analysis. Potential nodal structure of electricity price influences the future economic effectiveness of SG concept massively. This fact is manifested in formulated cost benefit analysis, presented in chapter 6.4. Presence of AMM / AMI elements in the grid should logically results in establishment of data management system, called by the author **data pooling system** (chapter 6.8). Such a system will be according to the author necessary for grid stability. This fact will eliminate the mentioned risk of grid overloading. It can partly eliminate problems with land purchase or easements.

As an important part of the methodology, the author identifies list of the most important costs and benefits (CBA)[37]. The costs presented in chapters 6.4.1 and 6.4.2 author identifies as inputs into SG subsystem. The benefits presented in chapters 6.4.3 and 6.4.4 author identifies as outputs from SG subsystem. The changes in installed capacity of intermittent distributed resources as well as changes in consumption (e.g. constituted by changing of customer´s habits of by growing amount of electric vehicles, etc.) represent changes in environment for SG subsystem. The described methods of market participants motivation represent the way of influencing the feedback of the SG subsystem an at the same time indirectly manage the SG subsystem development. Motivation systems are described in chapter 6.5[38].

7.1.5 Identification of Real Impacts of SG Implementation

Author identified lots of impacts that will represent opportunity for the future market participant´s behaviour. These findings originate in author´s systematic analysis of SG implementation.

7.1.5.1 Smart Tariff

In chapter 6.6 the smart tariff is presented as a condition for economical and sustainable development of the presented SG subsystem. As an important aspect (output) of SG implementation is according to author´s methodology (previously

[37] Author´s formulated cost benefit analysis represents enable the SG concept impacts valuation. The list is however not complete list of all existing potential costs and benefits. It summarized the important costs and benefits relevant for today´s conditions of energy branch.

[38] The formulated CBA is applied in chapter 6.5.4 on case study.

published in [59]) occurrence of local prices (called **smart local price – SLP**) chapter 6.6.1. To determine such SLP, it will be needed to create a brand new kind of market, called by the author **local balancing market (LBM)** parallel to current global market. Existence of such market can enable (B_{Market} benefit) which represents output form the SG subsystem as well as important motivation (feedback) for market participants. This market will associate more consumers, decentralized RES-E generators, accumulators or CHP and last but not least more traders in such a way which would allow determination of optimal SLP. Existence of more available traders in local balancing market complies with generally accepted doctrine of liberalization and market management Third Party Access Platform. From facts described in chapter 6.6 is obvious that the feedback, on short term as well as long term, is a very important aspect of SG implementation. This represents on one hand a tactic feedback usable for operative system management (dispatch) and on the other hand a strategic feedback provided by legislative system and mandatory law. According to author´s research the AMI platform (dispatching) will have to guarantee, that customer will not be constrained in its consumption in massive way. It will only optimize costs of consumption in some local area. The methodology of CBA is applied on example of B_{Market} evaluation (chapter 6.7.4). The exact value of this benefit is not possible to be calculated because of lack of relevant data. It can be set only parametrically by the analysis of reachable statistic data. The author uses data resulting from REMODECE project and calculates potential of B_{Market} which equals to 60% of household consumption as a minimum. In chapter 6.7.5 the potential of B_{Market} (as output of possible SG implemented in EIS) is presented and calculated regarding to author´s methodology.

For the system analysis it is apparent that utilizing B_{Market} would have impact in another part of the system – in the transmission and distribution grid. Therefore the author conducted another study in chapter 6.7.6. The potential impact on conductors dimensioning (as feedback of PHEV implementation and utilisation in EIS) is mentioned there. The impact of hybrid vehicles enlarges necessary capacity of conductors for at almost 30%.

7.1.5.2 Compliance of Grid Management

One important output of SG concept implementation would be according to the author of this thesis that the AMM allows demand management according to the needs of the trader. Therefore there should be the merger of the needs of trading and distribution (chapter 6.6.1). The optimally market-oriented model of smart grid management therefore presumes demand response upon trader (SLP management) limited by physical condition provided by DSO as a limiting condition. This fact requires data providing (datapooling, this concept described and published in [60]) between market participants and can be in contradiction with unbundling. The mentioned facts would require the appropriate legislation change (complying with hypotheses in chapter 1.2).

7.1.5.3 Data Energy Coupling (DEC) and System of Datapooling

According to the author SG concept should be implemented in the way of SWF maximization (chapter 4.2.5.1). According to the valuation methodology (chapter 6.4.3) benefits, especially B_{Market} B_{REG} would require instant access to data origination from AMM devices. The concept that will as a feedback from SG implementation emerge is called by the author **datapooling**. This concept would provide necessary data for market participantsand it is obvious that it represents direct impact of SG concept implementation.

Potential way of communication - the data energy coupling (DEC) would after implementation of SG represent opportunity for energy utilities to spread their commercial activities to the area of data transport because communication channels for relevant AMM data would require related infrastructure.

7.1.5.4 Local TPA

As it was many times mentioned above, the decentralization of energy branch connected with SG concept would accent local conditions in the grids. Access to the grid as well as to the market (see B_{Market} benefit) would need to be decentralized as well. The author called this concept local TPA and it represents following impact of SG concept implementation. After SG implementation, each market participant should have the opportunity to access the market platform to utilize potential benefits described above. Particular condition for behaviour will be set by local conditions in the grid and by behaviour of other local consumers. The necessary related legislation should be discussed in the future in more details.

7.2 Author´s Hypothesis

As it is obvious from the goals reached in this thesis, the influence of SG implementation on EB will be massive. It would change status of market participants as elements of EB system. It will establish opportunities summarized in chapter 7.1.5 and market participants will have to adapt. The hypothesis *“that implementation of smart grids concept would influence energy branch as a system; all market participants and relationships between them as well”* is therefore confirmed. Real examples of such changes will in full extend appear after roll out of SG concept, if it will be forced by the EU. The first pieces of evidence are nevertheless visible today. European energy utilities are now orienting to customers with complex services and not only with electricity supply. These companies are massively investing into ICT systems, telecommunications, electric vehicles promotion, financial services, etc…[39]

[39] The evidences are apparent from offered services on web sites of particular utilities.

7.2.1 Sub hypothesis 1

This sub-hypothesis should manifest basic change constituted by the CG concept against today´s energy branch. Unbundling forced electricity distribution and its trading (retail) to be independent. But chapter 6.6.1 states that technical management of the electricity grid (dispatching), conducted in the way of grid stability, can differ from management of the commercial portfolio of consumers. Therefore the mentioned concept of datapooling must provide grid data regarding to this feature. Such data sharing would enable a change in behaviour of market participants. DSO would establish technical borders regarding to physical conditions and traders would be able to manage the behaviour of consumers by the means of motivation. The data sharing in this concept will prevent the independence of behaviour of DSO and trader. *"For successful implementation of grid management (demand response) in the SG concept the independent behaviour of distribution system operator and trader represents a problem."* This sub-hypothesis is therefore confirmed.

7.2.2 Sub hypothesis 2

Today´s electricity price structure is described in chapter 3.2. It is based on main features of electricity as a commodity as well as on its distribution channels. Described possibility of bottlenecks occurrence, real time measurement, data distribution systems and described generation / consumption management (demand response) would enable local differences in electricity price (chapter 6.7.2). Resulting possibility of consumers´ motivation would moreover force traders for special tariffs formulation. Regulated part of price can be adapted according to local conditions. The hypothesis that *"SG concept would enable brand new construction of electricity price, different from today´s one"* is therefore confirmed.

7.2.3 Sub hypothesis 3

The third sub-hypothesis *"SG concept would prepare environment for new status of electricity customer"* is confirmed by existence of smart tariff motivating them for consumption / generation management. The predicted concept LTPA fully complies with this sub-hypothesis.

8 Conclusions

Author´s methodology appears to be viable for smart technologies valuation. It identifies lots of outputs as well as aspects of feedback resulting from smart technologies implementation into EBS. Described motivation of market participants (chapter 5) represents way of system management and instrument for system feedback prediction. This feedback, described by the author, applied on system, is partly apparent in technology learning (chapter 3.7).

In today´s energy branch the examples of missing system analyses are apparent. For example the RES-E support schemes represent important aspect influences today´s TSO, DSO as well as electricity customers. These schemes results in massive increase of installed RES-E capacity. There is a feedback of the system that results in risk of overloading of transportation capacities[40]. According to author of this thesis, the mistake was inter alia that political force, succeeding with RES-E support, did not enforce necessary projects of corresponding transport capacities enlargement. Each aspect of the smart grids concept may be according to author´s research therefore considered from the systematic viewpoint[41].

8.1 Discussion

There are lots of unanswered questions waiting for real operation data. Ancillary services can for instance merge with AMM equipped resources using the appropriate trading system. This would enable TSO to utilize these resources for physical stability of the grid. Appropriate calculations of economic effectiveness as well as impacts to social welfare of such services will have to be provided by future research based on real operating data.

Additional potential output from implementation of future AMM devices (that can be seen an a systematic feedback) is potential reactive power smart management (RPSM). This fact could abandon the used concept of compensation behind the customer (comply with [67]).

Additional open question is most appropriate way of AMM financing. In chapters 6.4.1 and 6.4.2 there is written that major difference between CAPEX and OPEX expanses is in time simultaneousness. These CAPEX costs as system inputs are timely shifted from SG benefits as outputs (reduced by OPEX costs). Therefore appropriate way of financing methods shall be employed for that CAPEX. The possible financing methods according to chapter 3.5 must be considered regarding to the learning process mentioned in chapter 3.7. The methodology of AMM financing will be therefore needed for solving the time divergence between cash flow originating in AMM CAPEX and its progressive future discounted savings for electricity customers (published in [39]).

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[40] For instance growing amount of wind power plants installed in Northern Germany overload coss-border connections between Germany and Czech Republic because of transports of electricity from the north to the south of Europe [45]. In extremes it could result in total collapse of transmission grid under some unlike conditions. This threat can be prevent only by the appropriate measure which would represent feedback in compliance with author´s methodology.

[41] It is evidenced in chapter 6.1.2 that distributed or decentralized power industry will not be able to establish stability of the grid without stable global grids and functional mix of global resources, e.g. coal power plants, gas power plants, and nuclear power plants that will establish stability of global grid.

The significant conceptual change resulting from SG is that it will pull the consumers into real electricity trading at almost the spot market level. The determinant for these situations will be both a large supply of large RES-E installations supplying to the transmission network as well as supplies from small decentralized sources. Their growing share may then lead to the collapse of the price level in each local area and real price decoupling as per chapters 6.3.1 - 6.3.4. Such a situation is far different from the current model of centrally controlled systems. In other words, the grid with a large number of dispersed renewable energy sources and growing local consumption without extensive investment into network expansion will represent the network with many nuclei of minor importance, possessing different minor balances, different price levels and different responses to either energy network changes or weather changes. This fact will be the biggest strategic change in energy systems over the next decade.

The predicted price decoupling can result, according to the author of this thesis, in the need of establishment of Local Third Party Access (LTPA). This new concept of local concurrence of more traders can allow the introduction of SG in accordance with the accepted concept of TPA. The described concept of SG nevertheless presents not a final stage of development from the perspective of energy supply to end users because it does not consider the competition between different kinds of energy. Implicitly, however, the SG concept constitutes the potential for multiple energy sources concurrence (MESC). The little Combined Heat and Power (CHP) units consuming gas can substitute electricity consumption. These would come to the LTPA concept as a closing power source. From the known gas prices, the AMM systems would be able to calculate the costs of producing electricity in a decentralized CHP unit which also produces heat. In this case, it would already be a multi Smart Grid (MSG).

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Supplement A. Impact of ST to the Energy Sector

Legend: + + means very positive effect, + means positive effect, 0 means neutral, - means negative effect and - - means very negative effect. * Positive effect depends on the fact if the capital for massive investment costs will not be obtained only from one market segment. The resource of capital should be in the whole system.

Table 11. Provides a summary of effects for particular market participants

Effects	**Generation**	**Transmission and distribution**	**Trading**	**Consumption**
CCS	- -	0	0	-
SG*	+	+ +	+ +	+
AMM*	0	+ +	+	+
PHEV	0	+	0	+ +
New Types of Nuclear Reactors	+ +	0	0	0
Fusion reactor	+ +	-	0	0
D CHP	+	+ +	0	0
RES-E	+	- -	0	-
Super-conductors	0	+ +	0	0
Hydrogen	+	+	0	+
Accumulation	+	+	0	+

The table was prepared regarding to discussions with experts.

Supplement B. REMODECE Data Overview and Calculation

Table 12. Appliances consumption by single household during work day

Average Household			Work day																							
Time	**Unit**	**Average**	**0:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Total consumption power	**W**	2 944	**3 503**	**3 420**	**3 177**	**3 097**	**3 016**	**3 009**	**2 994**	**2 309**	**2 696**	**2 736**	**2 632**	**2 448**	**2 446**	**2 273**	**2 509**	**2 559**	**2 598**	**2 711**	**2 785**	**3 456**	**3 512**	**3 537**	**3 651**	**3 585**
A Accumulative	W	702	823,2	846,2	710,2	664,9	608,2	601,7	575,3	612	923,4	903,4	802,3	598,2	603,4	418,5	624,6	666	703,5	788,2	789,1	699,9	683	662,7	742,7	789,5
Water heater	W	322	381,0	345,0	223,0	195,0	164,0	163,0	141,0	229,0	621,0	617,0	500,0	314,0	287,0	255,0	287,0	227,0	237,0	333,0	410,0	330,0	324,0	359,0	389,0	385,0
Freezer	W	63	64,0	63,5	62,0	61,8	63,0	61,0	61,0	62,0	60,0	63,0	61,0	64,0	62,6	62,0	64,0	62,3	63,5	63,5	64,0	63,9	64,0	63,0	63,5	63,0
Fridge	W	36	38,2	35,1	35,6	34,1	34,3	34,0	34,5	34,2	35,5	35,5	35,2	35,5	34,8	35,5	35,8	36,1	36,0	37,7	37,5	36,6	39,0	37,9	38,8	38,5
Fridge freezer	W	47	49,0	47,6	46,6	47,0	44,9	44,7	44,8	44,8	45,9	45,9	46,1	47,7	46,0	47,0	46,8	46,6	47,0	48,0	48,6	50,4	52,0	51,8	50,4	50,0
Air - conditioning	W	234	291,0	355,0	343,0	327,0	302,0	299,0	294,0	242,0	161,0	142,0	160,0	137,0	173,0	19,0	191,0	294,0	320,0	306,0	229,0	219,0	204,0	151,0	201,0	253,0
B Non accumulative	W	78	84,4	63,5	24	14	7,2	9,9	11,25	17,2	47,8	95,6	100,2	115,7	93,7	105	103,2	101,5	99,9	81	113,8	102,1	114,1	129,8	144,4	104,4
Washing machine	W	24	18,4	13,5	6,5	4,0	3,0	3,5	3,8	7,0	17,8	40,5	44,0	44,5	38,0	34,0	33,8	26,0	24,5	24,0	36,5	34,1	34,1	32,4	32,6	20,4
Dishwasher	W	23	34,0	31,0	13,5	8,0	4,0	6,0	2,3	2,4	14,0	25,5	30,2	27,2	16,7	19,0	31,8	39,5	26,0	19,0	25,3	29,0	30,0	37,0	48,2	38,0
Clothes dryer	W	31	32,0	19,0	4,0	2,0	0,2	0,4	5,2	7,8	16,0	29,6	26,0	44,0	39,0	52,0	37,6	36,0	49,4	38,0	52,0	39,0	50,0	60,4	63,6	46,0
C Non shiftable appliances	W	246	302	218	150	124	107	104	114	136	182	194	186	191	206	206	238	248	251	298	338	361	422	451	471	398
Lighting secondary room	W	3	4,3	2,4	1,1	0,6	0,5	0,4	0,7	2,0	4,4	3,4	2,2	1,9	1,8	1,6	1,6	1,4	1,4	1,8	2,9	4,9	6,6	7,3	7,3	6,6
Lighting living room	W	4	8,4	4,0	1,8	1,0	0,7	0,6	0,7	1,2	2,3	2,1	2,0	2,0	2,0	1,9	1,9	2,0	2,2	3,0	5,1	8,0	11,0	14,0	15,6	13,2
TV Plasma	W	44	69,0	38,0	19,3	12,0	6,8	4,2	4,0	6,3	24,3	25,6	22,0	24,3	28,0	38,5	53,4	40,3	34,8	33,0	40,2	64,5	94,8	127,0	131,5	109,6
TV LCD	W	21	41,9	25,4	12,5	8,3	5,0	3,2	2,6	4,2	7,7	9,0	8,7	8,8	12,4	16,0	18,4	15,9	16,0	18,7	24,2	30,2	44,4	57,6	62,2	53,7
TV CRT	W	14	23,3	15,5	10,7	8,0	6,8	6,5	6,3	7,5	9,7	11,0	10,4	10,8	11,0	12,0	13,0	13,2	13,5	14,0	15,7	16,4	24,2	27,7	30,0	30,0
TV settopbox	W	9	9,5	9,2	8,2	8,1	8,1	8,0	8,0	8,1	8,4	8,5	8,5	8,6	8,8	8,9	8,9	8,9	8,9	8,9	9,0	9,2	10,1	10,9	11,2	10,7
HIFI and radio	W	5	5,0	4,8	4,6	5,0	4,1	4,0	4,4	4,6	5,0	5,2	5,2	5,1	5,2	5,3	5,3	5,2	5,2	5,2	5,5	5,8	5,8	5,8	5,6	5,4
CD/DVD recorder	W	3	2,7	2,5	2,3	2,3	2,2	2,2	2,2	2,2	2,4	2,6	2,5	2,5	2,5	2,4	2,5	2,5	2,4	2,4	2,7	2,8	2,8	3,0	3,3	3,1
Others*	W	49	57,6	53,7	42,1	38,3	34,4	34,1	33,4	36,5	54,9	56,8	51,9	43,1	43,0	34,8	46,0	48,4	50,2	55,6	59,1	55,4	58,1	59,2	64,7	61,5
Jug kettle	W	7	2,7	1,4	0,3	0,2	0,0	0,4	7,3	16,2	16,1	12,3	8,0	8,7	10,6	6,8	5,7	6,9	5,0	5,2	7,8	10,2	11,3	7,4	6,5	5,6
Microwave owen	W	3	2,1	1,1	0,9	0,9	1,1	1,9	2,3	2,5	3,0	3,0	1,8	2,3	5,1	5,8	4,1	3,5	3,3	2,5	2,8	4,4	5,7	3,3	3,0	2,3
Electric cooker	W	23	3,0	0,2	0,1	0,1	0,2	2,7	8,0	6,0	2,3	7,0	13,1	12,3	21,0	18,5	20,5	40,5	37,0	74,3	78,8	63,5	57,0	40,0	43,8	13,0
Desktop PC with monitor	W	30	42,0	33,3	25,0	20,3	18,7	16,7	15,9	15,5	16,0	17,2	21,4	22,2	24,4	25,1	26,6	28,4	31,9	37,9	40,3	44,4	47,0	50,0	51,0	49,2
Laptop	W	7	10,0	7,1	5,2	3,9	3,0	2,8	2,8	2,8	3,3	4,1	4,6	5,2	5,8	6,0	6,1	6,7	7,0	7,8	8,2	8,9	10,4	11,6	12,8	11,8
Router	W	5	5,1	4,7	4,7	4,8	4,6	4,6	4,6	4,8	5,1	4,8	4,8	4,9	4,9	4,9	4,9	5,0	5,1	5,2	5,6	5,6	5,8	6,0	6,0	5,6
Printer	W	4	3,6	3,6	3,6	3,5	3,5	3,6	3,5	3,5	3,6	3,5	3,7	3,7	3,7	3,9	3,7	3,7	3,8	3,9	3,7	3,9	3,8	3,7	3,8	3,7
Wireless local area nwtwork	W	7	6,0	5,9	5,9	6,0	6,4	6,8	6,7	6,7	6,7	6,6	5,8	5,8	5,8	5,8	6,4	6,6	6,7	7,5	7,4	7,4	7,9	7,6	6,4	6,2
Vacuum cleaner	W	8	5,0	4,0	0,8	0,5	0,5	0,5	0,5	5,3	6,1	10,3	9,0	17,5	9,0	6,9	7,9	8,0	16,0	10,5	18,5	14,2	14,3	8,0	5,2	6,0
Mobil phone charger	W	1	0,8	0,8	0,7	0,7	0,6	0,7	0,6	0,7	0,6	0,7	0,9	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,1	1,0	1,0	1,0	1,0
D Central heating - Accumulative	W	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543
PHEV	W	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375
E PHEV (off peak, night)	W	375	750	750	750	750	750	750	750	0	0	0	0	0	0	0	0	0	0	0	0	750	750	750	750	750
F Standby	W	9,28																								

Table 13. Appliances consumption by single household during weekend day

Average Household													Weekend day													
Time	**Unit**	**Average**	**0:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Total consumption power	**W**	2 885	**3 422**	**3 288**	**3 151**	**3 010**	**2 906**	**2 853**	**2 886**	**2 112**	**2 062**	**2 138**	**2 385**	**2 669**	**2 675**	**2 637**	**2 740**	**2 706**	**2 728**	**2 680**	**2 710**	**3 455**	**3 483**	**3 544**	**3 554**	**3 446**
Accumulative	W	615	678	672	666	575	498	454	485	454	391	402	551	619	655	656	760	745	740	693	723	669	649	682	703	648
Waret heater	W	260	259,0	261,0	249,0	155,0	108,0	92,0	94,0	112,0	122,0	143,0	260,0	331,0	370,0	399,0	411,0	345,0	316,0	282,0	366,0	340,0	330,0	310,0	323,0	273,0
Freezer	W	54	52,1	54,0	55,8	53,0	53,8	53,6	53,7	53,9	52,2	54,3	54,7	54,0	55,8	54,3	54,0	55,7	56,0	57,0	56,0	52,2	57,8	56,8	54,0	53,0
Fridge	W	35	35,2	34,5	35,0	33,1	33,3	33,0	34,0	33,5	31,6	33,8	34,0	35,1	35,0	36,4	35,0	35,5	35,4	37,0	37,5	37,5	38,1	37,0	36,9	36,0
Fridge freezer	W	48	49,0	47,6	46,6	47,0	44,9	44,7	44,8	44,8	44,7	45,9	48,6	47,7	48,0	49,6	49,6	49,0	49,5	50,4	49,8	50,7	51,0	52,3	51,0	51,0
Air - conditioning	W	217	283,0	275,0	280,0	287,0	258,0	231,0	258,0	210,0	140,0	125,0	154,0	151,0	146,0	117,0	210,0	260,0	283,0	267,0	214,0	189,0	172,0	226,0	238,0	235,0
Non accumulative	W	86	131	107	28	14	7	8	3	4	11	41	86	150	159	126	140	127	99	86	99	126	140	104	151	103
Washing machine	W	19	10,0	7,0	4,0	3,5	1,5	2,0	1,2	2,3	5,8	19,0	36,0	52,2	50,0	40,0	28,0	27,0	21,0	19,2	23,0	21,7	22,5	19,5	18,7	13,0
Dishwasher	W	25	25,0	26,0	16,0	6,0	2,0	5,7	1,5	1,9	5,0	18,2	25,9	33,6	36,0	32,5	42,0	51,8	37,0	33,5	27,0	30,2	35,5	38,5	33,8	30,4
Clothes dryer	W	42	96,2	74,0	8,0	4,4	3,8	0,4	0,2	0,2	0,6	4,2	24,4	64,6	73,4	53,6	69,6	48,4	41,4	33,0	48,6	74,0	82,0	46,0	98,0	60,0
Non shiftable appliances	W	266	320	216	163	128	108	97	106	110	117	152	204	357	317	312	297	291	345	357	345	367	401	464	407	402
Lighting secondary room	W	2	3,8	2,2	1,2	0,7	0,5	0,5	0,5	0,7	1,4	2,1	2,2	2,1	2,0	2,1	1,8	1,6	1,7	2,0	3,0	4,6	5,7	6,0	5,8	5,1
Lighting living room	W	4	8,0	4,7	2,3	1,3	1,0	0,7	0,6	0,7	1,0	1,6	2,4	2,7	2,9	3,0	2,0	2,0	2,6	3,3	5,2	8,2	10,6	12,0	12,8	11,8
TV Plasma	W	48	79,2	40,0	27,2	17,6	10,6	7,8	6,2	6,2	14,3	26,1	32,2	36,5	43,0	46,8	56,2	52,0	50,5	54,2	61,0	74,5	92,0	104,0	108,4	104,0
TV LCD	W	25	37,9	28,2	18,0	10,9	6,6	5,0	3,6	3,1	4,5	7,4	14,0	16,7	18,7	23,0	28,5	30,0	32,0	28,8	31,7	39,2	46,2	54,4	58,0	54,4
TV CRT	W	15	22,6	16,2	11,0	8,5	7,5	6,5	6,0	6,0	7,5	10,3	13,2	13,1	14,0	14,5	15,5	16,1	15,1	16,2	17,5	20,2	24,2	27,1	28,1	27,8
TV settopbox	W	9	9,6	8,9	8,5	8,3	8,1	8,1	8,0	8,0	8,2	8,4	8,6	8,8	9,0	9,2	9,3	9,2	9,2	9,2	9,3	9,6	9,9	10,3	10,6	10,3
HIFI and radio	W	5	5,0	4,7	4,4	4,4	4,4	4,4	4,4	4,4	4,6	4,8	5,0	5,3	5,6	5,9	5,9	5,8	5,6	5,9	5,7	5,9	5,7	5,4	5,4	5,4
CD/DVD recorder	W	3	2,8	2,7	2,3	2,3	2,3	2,3	2,2	2,2	2,3	2,6	2,6	2,6	2,8	2,8	2,8	2,8	2,7	2,7	2,8	2,8	2,8	3,0	3,2	3,0
Others*	W	46	53,8	47,4	40,8	34,1	29,2	26,6	28,2	27,1	24,7	28,3	40,1	53,6	53,9	52,1	57,0	55,4	56,4	54,1	55,6	55,3	56,7	59,5	60,0	54,9
Jug kettle	W	7	4,0	1,5	2,3	0,4	0,5	0,5	1,8	4,2	11,4	17,0	15,6	15,8	14,7	7,3	6,6	7,2	7,6	6,7	6,6	6,8	7,1	10,0	6,6	3,1
Microwave owen	W	3	1,5	1,4	0,9	0,9	0,9	0,9	1,1	1,5	2,5	2,7	2,3	4,2	6,9	5,8	6,9	5,1	2,4	2,2	2,4	6,2	5,8	2,4	3,6	2,5
Electric cooker	W	36	24,3	2,0	0,2	0,1	0,0	0,0	10,1	13,7	0,3	0,2	18,2	114,0	69,8	62,0	30,8	30,0	78,2	100,0	68,3	55,0	44,0	82,0	20,0	39,0
Desktop PC with monitor	W	30	39,5	33,2	25,0	20,2	18,7	16,7	16,0	15,4	15,9	17,1	21,4	22,2	24,3	25,2	26,7	28,5	31,9	37,9	40,3	44,4	47,0	50,0	51,0	49,5
Laptop	W	7	9,4	6,5	3,8	2,8	2,4	2,2	2,0	2,0	2,2	2,9	4,2	6,1	7,6	8,6	8,7	8,9	8,9	8,6	9,0	9,3	10,2	11,4	11,8	10,9
Router	W	5	6,5	5,0	4,6	4,5	4,4	4,4	4,4	4,4	4,6	5,3	5,8	5,8	5,8	6,1	5,6	5,3	5,4	5,9	6,0	6,0	6,0	6,2	6,2	6,4
Printer	W	4	3,5	3,5	3,4	3,4	3,5	3,4	3,4	3,5	3,4	3,7	3,8	4,2	3,9	3,9	3,9	3,8	4,0	3,9	3,8	3,7	3,6	3,7	3,7	3,6
Wireless local area nwtwork	W	6	6,5	6,6	6,3	6,4	6,4	6,5	6,4	6,4	6,4	6,4	6,3	6,4	6,4	6,5	6,6	6,6	6,3	6,4	6,5	6,5	6,2	6,2	6,3	6,5
Vacuum cleaner	W	9	0,9	0,7	0,3	0,0	0,0	0,0	0,0	0,0	0,8	4,0	5,1	35,7	25,0	26,0	21,5	19,3	23,2	8,2	9,0	7,6	15,9	9,7	4,5	2,5
Mobil phone charger	W	1	0,9	0,7	0,8	0,7	0,7	0,8	0,7	0,7	0,8	0,9	0,9	1,0	1,1	1,1	1,1	1,2	1,4	1,2	1,1	1,1	1,2	1,2	1,1	1,1
Central heating	W	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543	1 543
PHEV	W	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375	375
PHEV (off peak)	W	375	750	750	750	750	750	750	750	0	0	0	0	0	0	0	0	0	0	0	0	750	750	750	750	750

Table 14. Appliances consumption by average household during work day

	Average Household				Work day																							
	Time	Ownership [%]	**Unit**	**Average**	**0:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
	Total consumption power		**W**	521	**600**	**548**	**460**	**432**	**408**	**408**	**409**	**368**	**505**	**543**	**517**	**473**	**459**	**427**	**475**	**484**	**490**	**544**	**600**	**648**	**671**	**674**	**705**	**647**
A	Accumulative		W	189	213,44	206,82	174,40	164,72	153,29	151,81	146,34	163,12	254,56	252,41	224,35	177,83	172,36	150,23	176,04	171,03	176,66	201,58	213,54	193,13	193,58	195,63	207,96	211,45
	Water heater	25%	W	80	95,25	86,25	55,75	48,75	41,00	40,75	35,25	57,25	155,25	154,25	125,00	78,50	71,75	63,75	71,75	56,75	59,25	83,25	102,50	82,50	81,00	89,75	97,25	96,25
	Freezer	25%	W	16	16,00	15,88	15,50	15,45	15,75	15,25	15,25	15,50	15,00	15,75	15,25	16,00	15,65	15,50	16,00	15,58	15,88	15,88	16,00	15,98	16,00	15,75	15,88	15,75
	Fridge	90%	W	32	34,38	31,59	32,04	30,69	30,87	30,60	31,05	30,78	31,95	31,95	31,68	31,95	31,32	31,95	32,22	32,49	32,40	33,93	33,75	32,94	35,10	34,11	34,92	34,65
	Fridge freezer	79%	W	38	38,71	37,60	36,81	37,13	35,47	35,31	35,39	35,39	36,26	36,26	36,42	37,68	36,34	37,13	36,97	36,81	37,13	37,92	38,39	39,82	41,08	40,92	39,82	39,50
	Air - conditioning	10%	W	23	29,10	35,50	34,30	32,70	30,20	29,90	29,40	24,20	16,10	14,20	16,00	13,70	17,30	1,90	19,10	29,40	32,00	30,60	22,90	21,90	20,40	15,10	20,10	25,30
B	Non accumulative		W	43	44,44	35,40	15,15	9,04	5,30	7,03	5,97	9,60	28,47	59,55	64,98	67,22	53,71	53,95	58,69	55,74	48,77	41,75	60,14	57,54	60,35	65,11	72,77	51,56
	Washing machine	94%	W	23	17,30	12,69	6,11	3,76	2,82	3,29	3,53	6,58	16,73	38,07	41,36	41,83	35,72	31,96	31,77	24,44	23,03	22,56	34,31	32,05	32,05	30,46	30,64	19,18
	Dishwasher	61%	W	14	20,74	18,91	8,24	4,88	2,44	3,66	1,40	1,46	8,54	15,56	18,42	16,59	10,19	11,59	19,40	24,10	15,86	11,59	15,43	17,69	18,30	22,57	29,40	23,18
	Clothes dryer	20%	W	6	6,40	3,80	0,80	0,40	0,04	0,08	1,04	1,56	3,20	5,92	5,20	8,80	7,80	10,40	7,52	7,20	9,88	7,60	10,40	7,80	10,00	12,08	12,72	9,20
					0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C	Non shiftable appliances		W	145	162	126	91	78	69	69	76	90	117	126	122	123	128	118	135	152	159	195	221	218	237	233	244	204
	Lighting secondary room	100%	W	3	4,30	2,40	1,08	0,60	0,46	0,40	0,70	2,00	4,36	3,41	2,20	1,90	1,77	1,63	1,55	1,43	1,41	1,78	2,90	4,90	6,55	7,26	7,30	6,55
	Lighting living room	100%	W	4	8,40	4,00	1,80	1,00	0,70	0,57	0,70	1,18	2,30	2,10	2,00	2,00	1,95	1,88	1,90	1,95	2,18	3,03	5,10	7,95	11,03	14,00	15,60	13,20
	TV Plasma	15%	W	7	10,35	5,70	2,90	1,80	1,02	0,63	0,60	0,95	3,65	3,84	3,30	3,65	4,20	5,78	8,01	6,05	5,22	4,95	6,03	9,68	14,22	19,05	19,73	16,44
	TV LCD	40%	W	8	16,76	10,16	5,00	3,32	2,00	1,28	1,04	1,68	3,08	3,60	3,48	3,52	4,96	6,40	7,36	6,36	6,40	7,48	9,68	12,08	17,76	23,04	24,88	21,48
	TV CRT	38%	W	5	8,85	5,89	4,07	3,04	2,58	2,47	2,39	2,85	3,69	4,18	3,95	4,10	4,18	4,56	4,94	5,02	5,13	5,32	5,97	6,23	9,20	10,53	11,40	11,40
	TV settopbox	33%	W	3	3,14	3,02	2,71	2,67	2,66	2,65	2,64	2,66	2,78	2,81	2,81	2,84	2,90	2,93	2,93	2,93	2,93	2,93	2,98	3,05	3,34	3,60	3,70	3,54
	HIFI and radio	72%	W	4	3,60	3,45	3,31	3,60	2,95	2,88	3,18	3,28	3,60	3,73	3,72	3,70	3,75	3,84	3,82	3,76	3,74	3,74	3,96	4,19	4,16	4,18	4,03	3,89
	CD/DVD recorder	67%	W	2	1,83	1,68	1,54	1,54	1,47	1,50	1,50	1,50	1,60	1,71	1,64	1,66	1,64	1,63	1,68	1,68	1,61	1,63	1,80	1,88	1,90	2,02	2,21	2,10
	Others*	100%	W	49	57,60	53,68	42,10	38,25	34,41	34,07	33,38	36,46	54,90	56,79	51,85	43,07	43,00	34,75	45,98	48,35	50,22	55,60	59,11	55,37	58,05	59,22	64,66	61,53
	Jug kettle	50%	W	3	1,35	0,70	0,17	0,08	0,00	0,20	3,63	8,10	8,05	6,15	3,99	4,35	5,30	3,40	2,85	3,47	2,50	2,62	3,89	5,09	5,65	3,70	3,25	2,80
	Microwave owen	67%	W	2	1,41	0,74	0,61	0,60	0,74	1,27	1,54	1,70	2,01	2,00	1,21	1,54	3,42	3,90	2,72	2,31	2,19	1,65	1,88	2,93	3,82	2,19	2,00	1,52
	Electric cooker	80%	W	19	2,40	0,16	0,08	0,08	0,16	2,16	6,40	4,80	1,84	5,60	10,48	9,84	16,80	14,80	16,40	32,40	29,60	59,44	63,04	50,80	45,60	32,00	35,04	10,40
	Desktop PC with monitor	59%	W	18	24,78	19,65	14,75	11,98	11,03	9,85	9,38	9,15	9,44	10,15	12,63	13,10	14,40	14,81	15,69	16,76	18,82	22,36	23,78	26,20	27,73	29,50	30,09	29,03
	Laptop	47%	W	3	4,69	3,34	2,44	1,84	1,41	1,32	1,32	1,32	1,56	1,93	2,15	2,44	2,73	2,83	2,88	3,13	3,27	3,66	3,86	4,18	4,86	5,47	6,03	5,55
	Router	48%	W	2	2,45	2,26	2,25	2,30	2,19	2,19	2,20	2,31	2,44	2,30	2,30	2,34	2,35	2,36	2,35	2,40	2,42	2,49	2,68	2,70	2,80	2,88	2,88	2,69
	Printer	67%	W	2	2,41	2,41	2,41	2,37	2,35	2,38	2,35	2,35	2,38	2,37	2,51	2,47	2,47	2,63	2,49	2,45	2,55	2,61	2,46	2,61	2,53	2,48	2,51	2,48
	Wireless local area nwtwork	33%	W	2	1,98	1,95	1,96	1,97	2,11	2,24	2,21	2,20	2,19	2,16	1,91	1,91	1,91	1,91	2,12	2,18	2,21	2,48	2,46	2,44	2,61	2,51	2,12	2,05
	Vacuum cleaner	100%	W	8	5,00	4,00	0,80	0,50	0,50	0,50	0,50	5,30	6,10	10,30	9,00	17,50	9,00	6,90	7,90	8,00	16,00	10,50	18,50	14,20	14,30	8,00	5,20	6,00
	Mobil phone charger	100%	W	1	0,80	0,77	0,70	0,70	0,64	0,66	0,62	0,65	0,62	0,73	0,90	1,00	1,03	1,04	1,00	1,00	1,00	1,00	0,98	1,05	1,03	1,00	1,01	0,96
D	Central heating - Accumulative	7%	W	105	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22
	PHEV	10%	W	38	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50
E	PHEV (off peak, night)	10%	W	38	75,00	75,00	75,00	75,00	75,00	75,00	75,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	75,00	75,00	75,00	75,00	75,00

Table 15. Appliances consumption by average household during weekend day

Average Household																Weekend day											
Time	Ownership [%]	**Unit**	**Average**	**0:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Total consumption power		**W**	511	**570**	**512**	**461**	**411**	**381**	**370**	**380**	**308**	**303**	**348**	**443**	**615**	**585**	**569**	**557**	**542**	**567**	**557**	**559**	**635**	**651**	**680**	**638**	**610**
A Accumulative		W	170	176,47	174,90	172,51	147,62	131,69	124,51	128,72	128,02	121,30	128,51	163,07	180,62	190,47	196,97	207,93	196,84	192,27	184,57	199,99	190,75	188,73	188,92	191,55	177,69
Water heater	25%	W	65	64,75	65,25	62,25	38,75	27,00	23,00	23,50	28,00	30,50	35,75	65,00	82,75	92,50	99,75	102,75	86,25	79,00	70,50	91,50	85,00	82,50	77,50	80,75	68,25
Freezer	25%	W	14	13,03	13,50	13,95	13,25	13,45	13,40	13,43	13,48	13,05	13,58	13,68	13,50	13,95	13,58	13,50	13,93	14,00	14,25	14,00	13,05	14,45	14,20	13,50	13,25
Fridge	90%	W	32	31,68	31,05	31,50	29,79	29,97	29,70	30,60	30,15	28,44	30,42	30,60	31,59	31,50	32,76	31,50	31,95	31,86	33,30	33,75	33,75	34,29	33,30	33,21	32,40
Fridge freezer	79%	W	38	38,71	37,60	36,81	37,13	35,47	35,31	35,39	35,39	35,31	36,26	38,39	37,68	37,92	39,18	39,18	38,71	39,11	39,82	39,34	40,05	40,29	41,32	40,29	40,29
Air - conditioning	10%	W	22	28,30	27,50	28,00	28,70	25,80	23,10	25,80	21,00	14,00	12,50	15,40	15,10	14,60	11,70	21,00	26,00	28,30	26,70	21,40	18,90	17,20	22,60	23,80	23,50
B Non accumulative		W	41	43,89	37,24	15,12	7,83	3,39	5,44	2,08	3,36	8,62	29,80	54,52	82,48	83,64	68,15	65,86	66,66	50,59	45,08	47,81	53,62	59,21	51,02	57,80	42,76
Washing machine	94%	W	18	9,40	6,58	3,76	3,29	1,41	1,88	1,13	2,16	5,45	17,86	33,84	49,07	47,00	37,60	26,32	25,38	19,74	18,05	21,62	20,40	21,15	18,33	17,58	12,22
Dishwasher	61%	W	15	15,25	15,86	9,76	3,66	1,22	3,48	0,92	1,16	3,05	11,10	15,80	20,50	21,96	19,83	25,62	31,60	22,57	20,44	16,47	18,42	21,66	23,49	20,62	18,54
Clothes dryer	20%	W	8	19,24	14,80	1,60	0,88	0,76	0,08	0,04	0,04	0,12	0,84	4,88	12,92	14,68	10,72	13,92	9,68	8,28	6,60	9,72	14,80	16,40	9,20	19,60	12,00
				0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
C Non shiftable appliances		W	157	169	120	93	75	65	60	69	72	68	85	120	246	206	199	178	174	219	223	206	210	223	260	209	209
Lighting secondary room	100%	W	2	3,75	2,23	1,23	0,70	0,50	0,45	0,45	0,72	1,40	2,05	2,20	2,10	2,00	2,08	1,80	1,60	1,67	2,00	2,97	4,57	5,70	6,00	5,83	5,10
Lighting living room	100%	W	4	8,00	4,70	2,28	1,30	1,00	0,70	0,60	0,70	1,00	1,60	2,35	2,70	2,90	3,00	2,00	2,00	2,60	3,27	5,18	8,20	10,62	12,00	12,80	11,80
TV Plasma	15%	W	7	11,88	6,00	4,08	2,64	1,59	1,17	0,93	0,93	2,15	3,92	4,83	5,48	6,45	7,02	8,43	7,80	7,58	8,13	9,15	11,18	13,80	15,60	16,26	15,60
TV LCD	40%	W	10	15,16	11,28	7,20	4,36	2,64	2,00	1,44	1,24	1,80	2,96	5,60	6,68	7,48	9,20	11,40	12,00	12,80	11,52	12,68	15,68	18,48	21,76	23,20	21,76
TV CRT	38%	W	6	8,59	6,16	4,18	3,23	2,85	2,47	2,28	2,28	2,85	3,91	5,02	4,98	5,32	5,51	5,89	6,12	5,74	6,16	6,65	7,68	9,20	10,30	10,68	10,56
TV settopbox	33%	W	3	3,17	2,94	2,81	2,74	2,68	2,67	2,65	2,65	2,72	2,77	2,84	2,90	2,96	3,03	3,07	3,05	3,05	3,05	3,07	3,17	3,27	3,41	3,48	3,41
HIFI and radio	72%	W	4	3,60	3,36	3,18	3,15	3,17	3,16	3,16	3,17	3,31	3,47	3,60	3,82	4,03	4,25	4,25	4,18	4,06	4,21	4,10	4,25	4,13	3,89	3,87	3,89
CD/DVD recorder	67%	W	2	1,88	1,81	1,54	1,54	1,51	1,51	1,49	1,49	1,54	1,71	1,75	1,74	1,84	1,88	1,86	1,84	1,81	1,81	1,86	1,88	1,87	2,00	2,15	2,04
Others*	100%	W	46	53,77	47,38	40,85	34,12	29,19	26,65	28,24	27,09	24,70	28,34	40,07	53,62	53,88	52,11	56,98	55,39	56,40	54,12	55,55	55,35	56,65	59,55	60,03	54,92
Jug kettle	50%	W	3	2,00	0,75	1,15	0,20	0,27	0,25	0,88	2,10	5,69	8,50	7,82	7,90	7,35	3,65	3,30	3,58	3,80	3,35	3,30	3,40	3,54	5,00	3,32	1,55
Microwave owen	67%	W	2	0,97	0,91	0,58	0,60	0,61	0,60	0,73	1,02	1,68	1,83	1,55	2,81	4,59	3,85	4,64	3,44	1,61	1,50	1,61	4,14	3,85	1,57	2,38	1,65
Electric cooker	80%	W	29	19,44	1,60	0,16	0,08	0,00	0,00	8,08	10,96	0,24	0,16	14,56	91,20	55,84	49,60	24,64	24,00	62,56	80,00	54,64	44,00	35,20	65,60	16,00	31,20
Desktop PC with monitor	59%	W	18	23,31	19,59	14,75	11,92	11,03	9,85	9,44	9,09	9,38	10,09	12,63	13,10	14,34	14,87	15,75	16,82	18,82	22,36	23,78	26,20	27,73	29,50	30,09	29,21
Laptop	47%	W	3	4,42	3,04	1,79	1,32	1,12	1,02	0,93	0,95	1,02	1,36	1,97	2,86	3,58	4,04	4,09	4,16	4,16	4,04	4,23	4,37	4,79	5,35	5,55	5,14
Router	48%	W	3	3,12	2,39	2,21	2,16	2,11	2,11	2,12	2,13	2,21	2,54	2,77	2,78	2,77	2,93	2,67	2,55	2,59	2,83	2,89	2,88	2,89	2,97	2,99	3,06
Printer	67%	W	2	2,36	2,36	2,28	2,28	2,31	2,28	2,28	2,32	2,30	2,49	2,53	2,78	2,60	2,61	2,63	2,57	2,68	2,63	2,55	2,51	2,41	2,45	2,48	2,41
Wireless local area nwtwork	33%	W	2	2,15	2,16	2,09	2,12	2,13	2,15	2,10	2,13	2,13	2,11	2,08	2,12	2,12	2,15	2,16	2,17	2,08	2,12	2,15	2,15	2,05	2,03	2,09	2,16
Vacuum cleaner	100%	W	9	0,90	0,70	0,30	0,00	0,00	0,00	0,00	0,00	0,80	4,00	5,10	35,70	25,00	26,00	21,50	19,30	23,20	8,20	9,00	7,60	15,90	9,70	4,50	2,50
Mobil phone charger	100%	W	1	0,90	0,72	0,77	0,70	0,70	0,79	0,71	0,68	0,75	0,87	0,93	1,00	1,05	1,10	1,08	1,15	1,40	1,21	1,12	1,11	1,22	1,20	1,13	1,08
D Central heating - Accumulative	7%	W	105	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22	105,22
PHEV	10%	W	38	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50	37,50
E PHEV (off peak, night)	10%	W	38	75,00	75,00	75,00	75,00	75,00	75,00	75,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	75,00	75,00	75,00	75,00	75,00

Table 16. Total shift able potential

	Unit	**Average**	**0:00**	**1:00**	**2:00**	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	**11:00**	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Average Household in Local Area (October-March)																										
Shiftable consumption	%	68,08%	62,82%	65,70%	66,73%	67,38%	67,61%	67,65%	66,11%	77,72%	78,50%	78,32%	77,98%	75,93%	74,27%	74,62%	73,72%	70,90%	69,78%	66,41%	65,32%	57,35%	55,96%	56,74%	57,06%	59,29%
Non-shiftable consumption	%	31,92%	37,18%	34,30%	33,27%	32,62%	32,39%	32,35%	33,89%	22,28%	21,50%	21,68%	22,02%	24,07%	25,73%	25,38%	26,28%	29,10%	30,22%	33,59%	34,68%	42,65%	44,04%	43,26%	42,94%	40,71%
Average Household in Local Area (April-September)																										
Shiftable consumption	%	61,47%	56,34%	59,09%	58,91%	59,14%	58,87%	58,92%	56,98%	70,94%	73,96%	74,09%	73,44%	70,45%	68,21%	68,13%	67,75%	64,44%	63,17%	59,87%	59,27%	50,52%	49,17%	50,09%	50,78%	52,75%
Non-shiftable consumption	%	38,53%	43,66%	40,91%	41,09%	40,86%	41,13%	41,08%	43,02%	29,06%	26,04%	25,91%	26,56%	29,55%	31,79%	31,87%	32,25%	35,56%	36,83%	40,13%	40,73%	49,48%	50,83%	49,91%	49,22%	47,25%

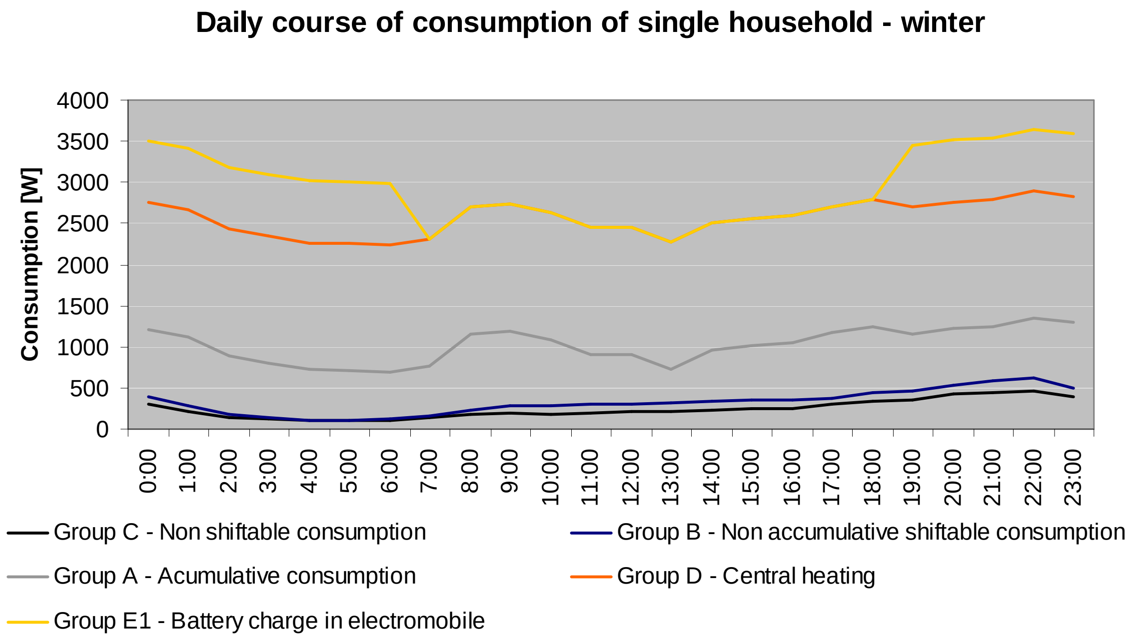

Fig 28. *Absolute single household appliances consumption (October – March)*

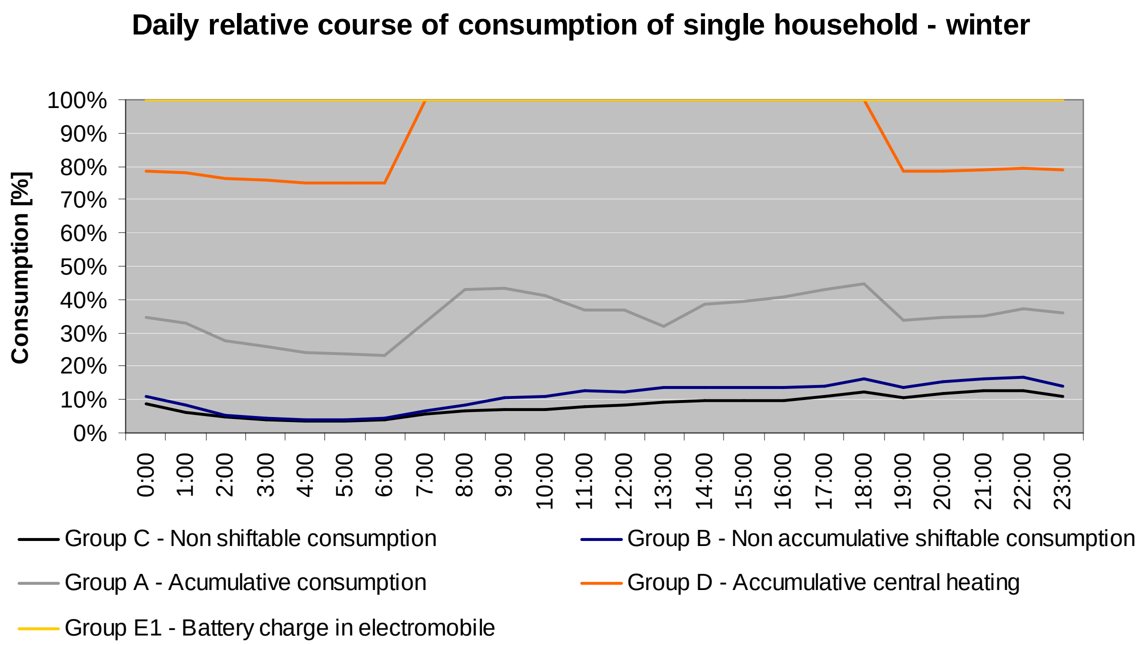

Fig 29. *Relative single household appliances consumption (October – March)*

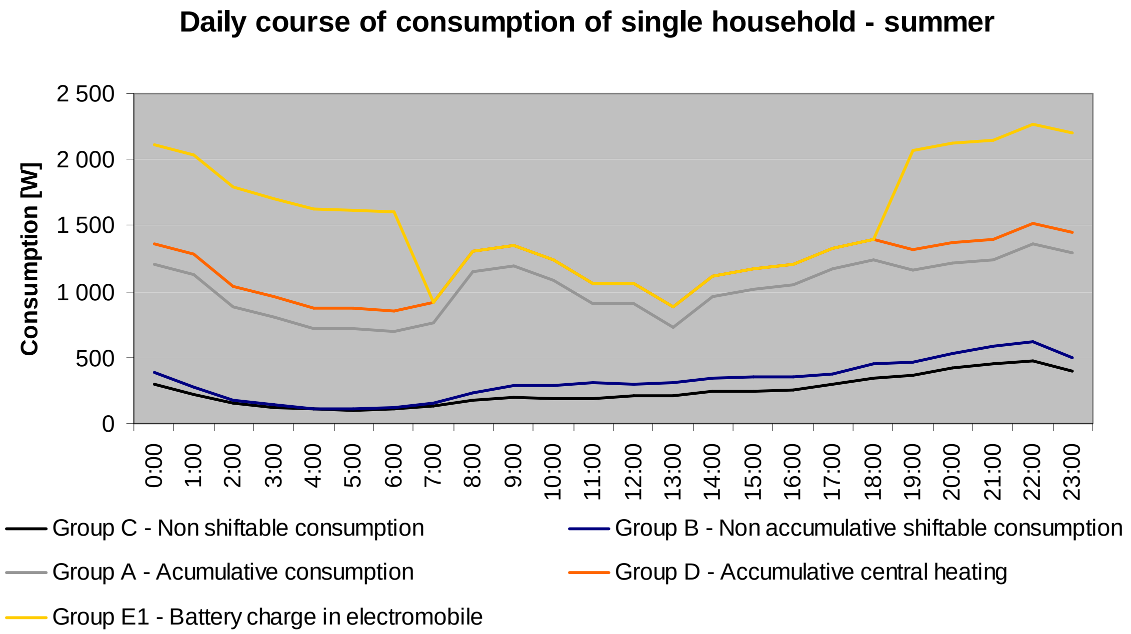

Fig 30. *Absolute single household appliances consumption (April – September)*

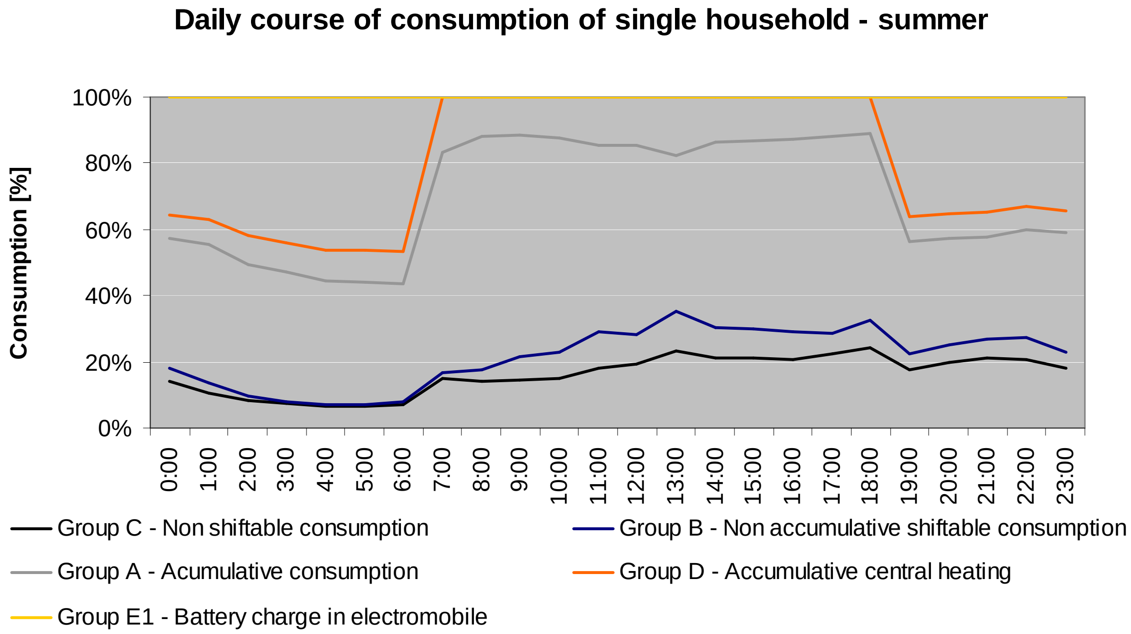

Fig 31. *Relative single household appliances consumption (April – September)*

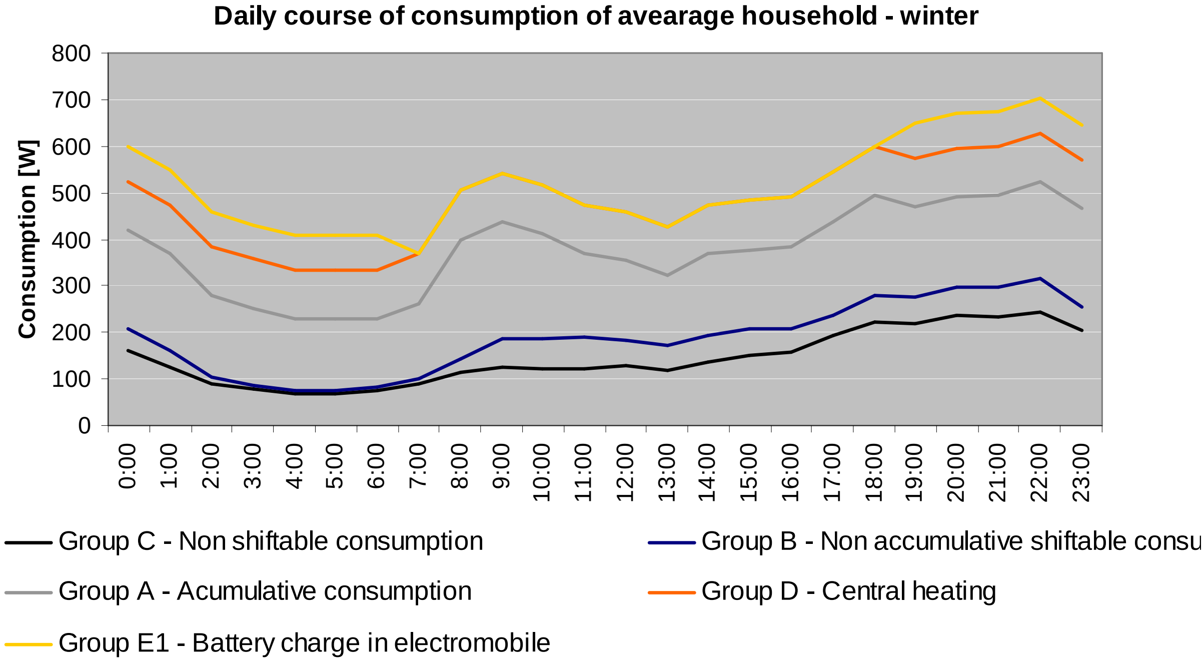

Fig 32. *Absolute average household appliances consumption (October – March)*

Average household consumption was obtained by multiplication of single household appliance consumption and average ownership as per Table 7.

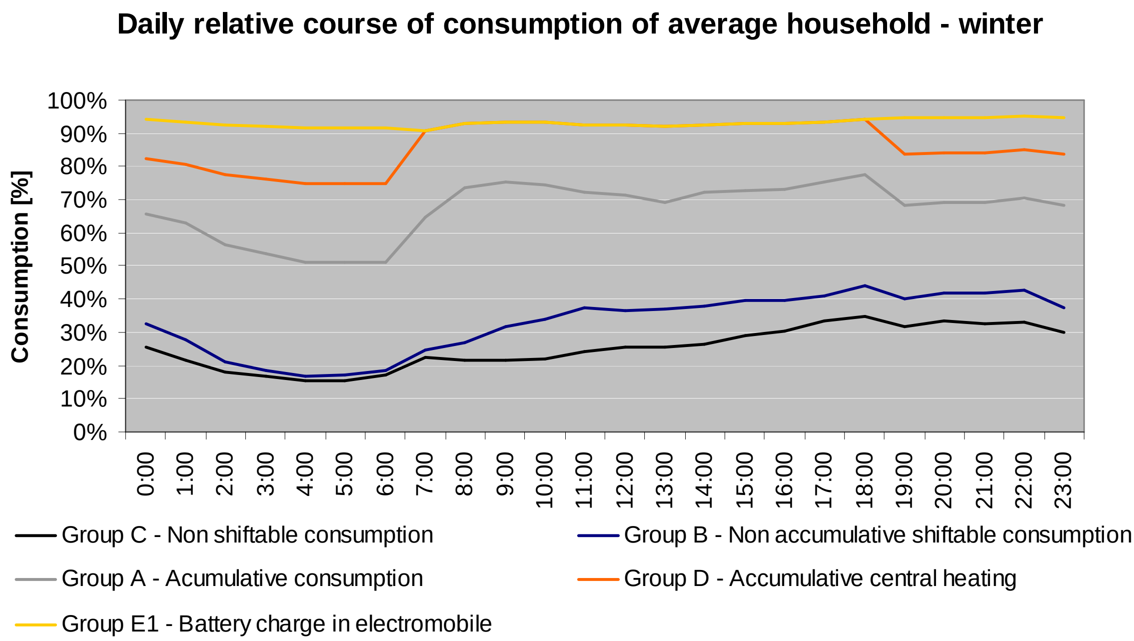

Fig 33. *Relative average household appliances consumption (October – March)*

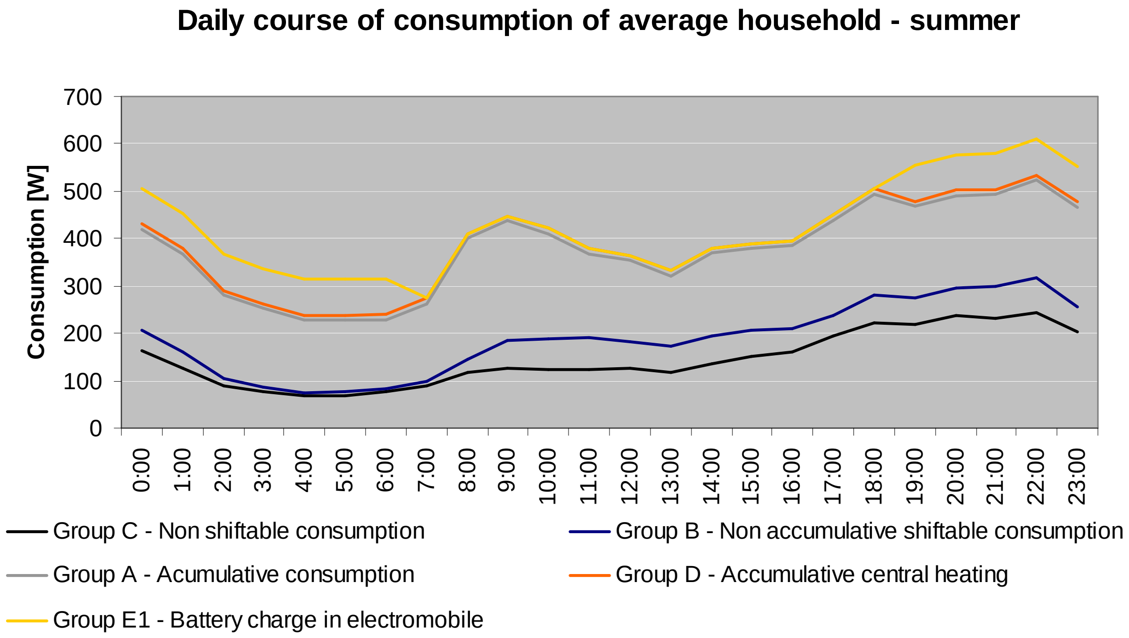

Fig 34. *Absolute average household appliances consumption (April – September)*

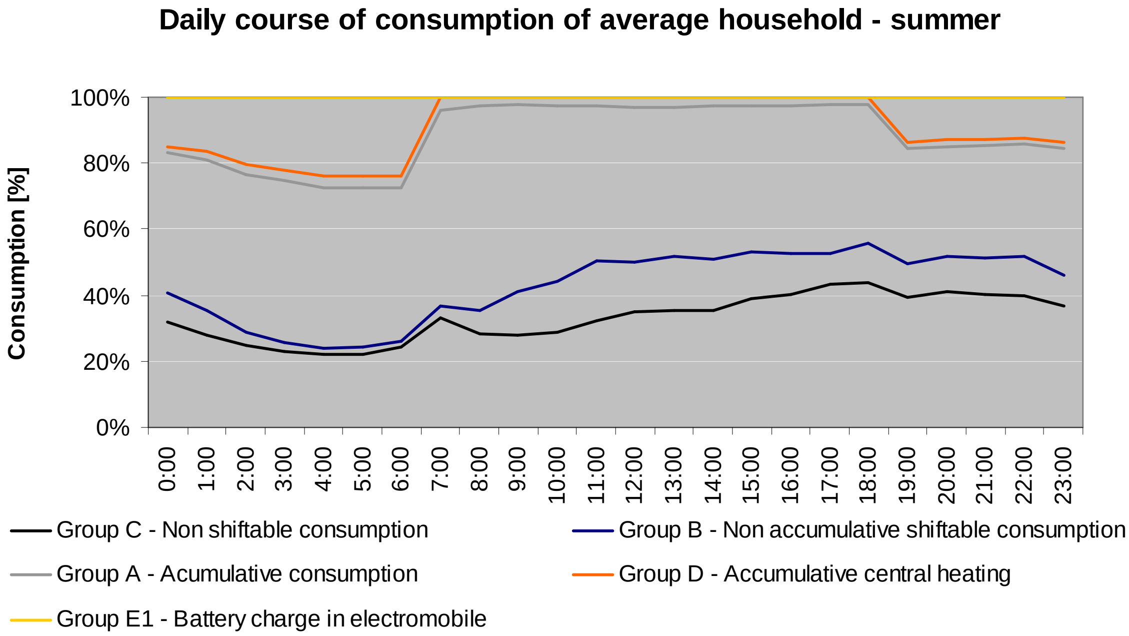

Fig 35. *Relative average household appliances consumption (April – September)*