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List of terms and acronyms

AMI	Advanced metering infrastructure
CHPP	Combined heat and power plants
CPP	Critical peak pricing
DLC	Direct load control
DOE	US. Department of energy
DR	Demand response
DSM	Demand side management
DSO	Distribution system operator
ECU	Experimental currency units
ESMA	European securities and markets authority
ETSO	European transmission system operator
FERC	US. Federal energy regulatory commission
GAO	US. Government accountability office
HPP	Hydro power plants
IEA	International energy agency
IP	Internet protocol
ISO	Independent system operator
NERC	National electricity regulation commission of Ukraine
NPP	Nuclear power plants
PLC	Power line communication
RTP	Real time pricing
TOU	Time-of-use
TPP	Thermal power plants
USD	United states dollar. Official exchange rate in the first half of 2013: 1USD= 0,772 EUR

Units

kW	kilowatt: a unit used to measure rate of energy transfer. 1kW = 1000 Watt
kWh	kilowatt per hour: a unit used to measure rate of energy use or production. 1 kWh = 1000 Watt/hour
GW	Gigawatt: a unit used to measure rate of energy use or production. 1 GW = 10^9 Watt

Abstract

In the current research the problem of inefficient energy consumption in low-income countries is elaborated. Inefficient consumption occurs due to low energy tariff levels and inefficient price policies. Therefore, the purpose of this research is to estimate the effectiveness of dynamic tariffs for the reduction of inefficient consumption, as well as to estimate the possibility of their implementation in low-income countries.
The research is based on the observation of the Ukrainian residential electricity market.
In order to fulfill purposes of the research, this study provides an analysis of the current technical, market and economic potential for the implementation of dynamic tariffs in the Ukrainian market, as well as a laboratory experiment, where the behavior of electricity consumers is examined under three different pricing environments: fixed price (FP); time-of-use tariff (TOU) and real-time pricing (RTP). Under fixed price, the tariff for electricity remains unchanged and depends only on the quantity of consumed electricity. The other two policies are dynamic tariffs, which aim to diminish the electricity consumption at time of high demand for electricity, or peak time.
Under each price policy participants of the experiment take decisions concerning the quantity of electricity they would like to consume.
In parallel with low tariff levels, the current research includes the problem of strong income polarization that is common for low-income countries. Therefore, participants of the experiment are divided into two income groups, and represent consumers of low- and high-income levels.
The statistical analysis of data obtained from the experiment has shown the following results. Under both dynamic tariffs participants have shifted their consumption from more "expensive" to the less "expensive" times. The peak electricity consumption was reduced by 55% under TOU tariff and by 46% under RTP. However, under both dynamic tariffs the peak load reduction was lower than it had been expected. The initial income level of participants did not affect their willingness to respond to price signals. The difference in demand response among income groups was statistically insignificant at the 95% confidence level.
Therefore, based on the results of the experiment, we may conclude that dynamic tariffs can be an effective tool for the reduction of peak electricity consumption in low-income countries. In spite of low tariff levels and strong income polarization, consumers of different income groups respond to price signals. As a result, demand for electricity decreases in peak time.
Nevertheless, the estimation of the possibility to implement dynamic tariffs in the Ukrainian electricity market has shown that Ukraine does not have sufficient technical and economic potential for their implementation. The main barriers for the implementation of dynamic tariffs in low-income countries are low level of energy sector privatization, and high costs for the necessary equipment. To foster development of dynamic tariffs in the Ukrainian residential electricity market, the technical and economic potential should be improved. The observation of the experience of different countries suggests that potential for the implementation of dynamic tariffs can be significantly improved through the liberalization of the energy market and inclusion of differential energy pricing system in a national plan of the effective energy use.

Zusammenfassung

Das Ziel dieser Arbeit ist die Untersuchung des Energiekonsums in Ländern mit niedrigem pro Kopf Einkommen. Die Hauptursache für ineffektiven Energiekonsum sind sehr niedrige Tarife. Die Einführung dynamischer Tarifmodelle für Elektrizität soll den Grad ineffektiver Konsumation reduzieren. Die folgende Arbeit wird daher eine empirische Analyse des Konsumentenverhaltens unter drei verschiedenen Tarifmodellen darstellen.
Die aktuelle Untersuchung ist auf dem ukrainischen Elektrizitätsmarkt aufgebaut.
Im folgenden Experiment werden Teilnehmer mit unterschiedlichen Einkommen entscheiden, wie viel Elektrizität sie jeweils aus fünfzehn verschiedenen Aufgaben konsumieren wollen. Die fünfzehn Aufgaben werden in zufälliger Reihenfolge angeboten, können aber in drei verschiedene Tarifmodelle gruppiert werden:
FP (ein fixer Preis), TOU (der Preis verändert sich mit der Zeit der Konsumation) und RTP (ein Echtzeitpreismodell – marktpreisabhängig). Unter dem Fixpreismodell verändert sich der Tarif nicht. Die beiden anderen Modelle sind dynamische Tarife, welche zum Ziel haben die Konsumation zu den teuren Spitzenzeiten zu reduzieren.
Parallel zu den niedrigen Stromtarifen geht die Studie auch auf, die, für Länder mit niedrigem pro Kopf Einkommen typische, starke Polarisation zwischen den Einkommensgruppen ein.
Die statistische Analyse der Ergebnisse zeigte folgende Ergebnisse. Bei den beiden dynamischen Tarifmodellen verschoben die Konsumenten ihren Verbrauch von „teuren" zu „billigeren" Zeitperioden.
Der Spitzenzeitverbrauch reduzierte sich um 55% beim TOU – Tarif und um 46% beim RTP – Tarif. Trotzdem war die Reduktion geringer als erwartet. Das Einkommensniveau der Teilnehmer hat ihre Bereitschaft auf Preissignale zu reagieren nicht beeinflusst. Der Unterschied in der Bedarfsreaktion zwischen den Einkommensgruppen war bei einer statistischen Sicherheit von 95% unbedeutend. Aufgrund der Resultate des Experiments lässt sich feststellen, dass dynamische Tarifmodelle ein effektives Werkzeug zur Reduktion von Lastspitzen in Ländern mit niedrigem pro Kopf Einkommen darstellen.
Trotz niedriger Tarife und hoher Einkommenspolarisation reagieren die Konsumenten der verschiedenen Einkommensgruppen auf Preissignale. Daraus resultierend sinkt die Nachfrage für Elektrizität zu Spitzenzeiten.
Trotzdem hat die Einschätzung der Möglichkeit dynamische Tarife im ukrainischen Markt ergeben, dass das technische und ökonomische Potential unzureichend ist.
Die größten Hürden sind der sehr niedrige Anteil privater Energieversorger und die hohen Kosten für die notwendige Ausrüstung. Um die Möglichkeiten zur Implementierung voranzutreiben sollte das technische und wirtschaftliche Potential verbessert werden. Die Erfahrung aus anderen Ländern zeigt, dass die Liberalisierung des Energiemarktes und die Einführung eines differenzierten Preissystems im nationalen Energieplan das Potential für die Verwirklichung dynamischer Tarife drastisch steigert.

1. Introduction

1.1. *Motivation*

The demand for electric power is not constant. There are certain times of the day when the demand level is much higher than in the rest of the day. For example, it is logical to expect that the electricity consumption is higher at day time and lower at night. The demand for electricity varies also during the day time. Periods of the day when the demand is high are called “peak” time.

Due to those variations, the demand for electricity might exceed the available supply (GAO, 2004). In such cases, the electricity providers order the generation of additional capacity from expensive “peakers” plants (Lave & Spees, 2007). There is a variety of power plants at which electricity is generated. According to their operation time, plants are divided into two types: “baseload” and “peakers”. Baseload plants are designed to operate all the time, while “peakers” usually operate just during peak time. Baseload plants have low costs for the electricity generation, but their construction is costly. In contrast, “peakers” are much less costly in construction, but the generated electricity is much more expensive (GAO, 2004). Costs for electricity generation from “peakers” are spread over all generated kilowatt-hours. This results in an increase of the average cost of electricity production, and so the wholesale price for electricity rises (Lave & Spees, 2007).

Therefore, the wholesale price varies according to the different market conditions. It rises in time of high demand, and decreases under low demand. In contrast, the retail price, at which electricity is sold to the end-consumers remains fixed.

Since the end-consumers pay a fixed retail tariff for electricity, independently from the consumption period, consumers do not have incentives to consume electricity effectively, and therefore a significant part of electricity is consumed in the “expensive” peak time.

The target of the current research is to estimate the effectiveness of dynamic tariffs or price-based demand response (DR) programs for the reduction of electricity consumption during peak time. The purpose of DR programs is to induce consumers to shift their consumption from more “expensive” to less “expensive” time (U.S Department of Energy, 2006).

Shifting of the electricity consumption to cheaper time periods would diminish the need to use costly power plants (Boisvert et al. 2002).

To reduce the consumption during peak hours, demand response programs are widely used in the USA, but their popularity in Europe is not high. Moreover, demand response programs almost do not exist in low-income countries (Toritti et al. 2009). Demand response programs require significant investments from governments and consumers (ERRA, 2008). However, the main barrier for implementing demand response programs is low tariff levels, which is common for low-income countries.

1.2. *Statement of the problem*

Ukraine is one of the most energy-intensive countries in Europe with annual electricity consumption of about 200 billion kWh. The main consumers are domestic industries and residential households. The residential households consume 26% of the generated electricity (DTEK, 2011).

Currently the residential households pay a fixed tariff for electricity. This price policy resulted in a continuously growing demand, where a significant amount of electricity is consumed in the "expensive" peak time. The inefficient price policy in Ukraine is complemented by the low level of electricity tariffs. Fixed tariffs paid by residential consumers cover only 60% of the generation costs.

The difference between generation costs and the retail tariff is compensated by the government. In 2011, almost USD 3, 5 billion was spent to subsidize the Ukrainian energy sector. In the presence of budgetary constraints, subsidies divert government funds away from the social and infrastructure spending (Tsarenko, 2008).

As in the majority of low-income countries, in Ukraine there is strong income polarization between income groups (UNDP Ukraine, 2010). 26 % of the Ukrainian population lives below poverty level. In spite of very low tariffs for electricity, it is problematic for this customer segment to pay the utility service. The difficulty that low-income consumers have in affording a further increase of tariffs is the main reason for refusing tariff reforms in Ukraine (Fankhauser & Tepic, 2005). However, underpricing of residential tariffs is a bad instrument to achieve distributional or welfare objectives. The low level of tariffs supports low-income households, but also favors wealthy consumers (Mitra &Atoyan, 2012).

The situation on the Ukrainian energy market becomes even worse due to the existing possibility not to pay electricity bills. Ukraine's law does not provide any punishment for non-payers, such as disconnection from energy supply, or sequestration of debt (Dodonov et al. 2001).

Implementing of demand response (DR) programs in the Ukrainian electricity market is an alternative solution for the increase of electricity tariffs. The establishment of price responsive demand will improve the Ukrainian energy sector. Demand response programs will reduce the outlay of government's funds for subsidizing the energy supply. This goal will be achieved through the reduction of the energy consumption during peak periods. Price responsive demand will also reduce the "non-payment" problem. It will be achieved by lowering the electricity bills. Due to the ability to shift the electricity consumption from more "expensive" to less "expensive" time, consumers may gain significant savings (Faruqui & Sergici, 2008). In the current research consumers' income levels and electricity tariffs are taken in proportion and represent the current situation on the Ukrainian electricity market. Therefore, dynamic tariffs are implemented on the base of the valid fixed tariff, which does not cover even the generation costs. It means that, under dynamic tariffs the price for electricity still remains significantly low compared to the average income level. As a result, low tariff level brings into a question whether consumers will respond to price signals.

1.3. *The research question*

The research question is: How do residential customers with different income levels respond to price signals?

Much information regarding the impact of DR programs on consumers' behavior is based on the analysis of the consumption behavior of average households. However, studying the impact of dynamic pricing on different income groups deserves special attention. The load profile of low-income customers differs from the load profile of the average household or wealth-situated consumer. This results in a different ability of low-income customers to respond to price signals (Faruqui & Sergici, 2010). It is reasonable to expect that low-income customers consume less energy than high-income customers; therefore they have a limited ability to shift their consumption from peak time to valley time. As a result, low-income customers will be hurt by dynamic pricing. However, five field experiments which were held in the USA to test the impact of dynamic pricing on low-income customers, have shown that the social vulnerable group of customers could benefit even without shifting their consumption (Faruqui & Palmer, 2011). Since low-income customers have a flatter load profile than the average residential customers, the low-income customers would immediately reach a bill reduction, even without shifting their load (Faruqui & Sergici, 2010).

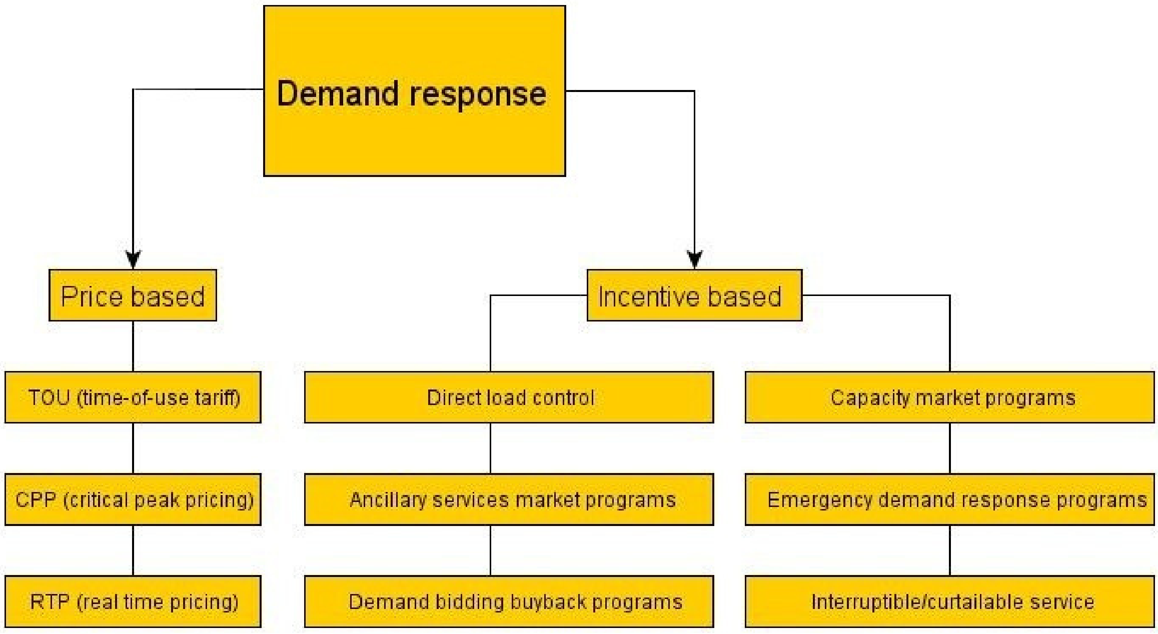
To answer the research question, this study provides a laboratory experiment, where the consumption behavior of consumers with different income levels is analyzed under three different price policies: fixed price (FP); time-of-use (TOU) and real-time pricing (RTP). The current research provides information regarding the response of low- and high-income consumers to price signals, and also makes a comparison among them. It also evaluates the current situation on the Ukrainian electricity market, as well as determines the main barriers that countries face to promote demand response programs. It evaluates market, technical and economic potential to implement demand response programs in the Ukrainian electricity market.

2. Necessity of demand response programs for the electricity market

2.1. *The demand response and its types*

In general, demand response means the voluntary changes in consumption, where the motivation for the response can be either price signals or incentives (ERRA, 2008).
A more precise definition gives the U.S. Department of Energy (DOE). According to the US DOE, demand response is a “change in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at time of high wholesale market prices or when system reliability is jeopardized” (U.S. Department of Energy, 2006 p.6).
The ETSO (European transmission system operator) defines demand response as “a voluntary temporary adjustment of power demand taken by the end-user as a response to a price signal (market price or tariffs) or taken by a counter-party based on an agreement with the end-user” (ETSO, 2007 p.2).
Demand response programs are grouped into two main categories: price-based demand response programs and incentive-based demand response programs (ERRA, 2008).

Figure 1: Demand response and its types



Source: own illustration on basis of ERRA, 2008 (ERRA, 2008, p.11-15)

Incentive-based demand response programs are based on the reduction of electricity consumption below a certain level according to an instruction or signal from the system operator. So, the electricity operator or a third-party takes the direct control over the consumer's load (MIT, 2011).The load reductions are necessary when the grid operator cannot provide the demanded capacity and reliability conditions are in danger, or when prices in the wholesale market are too high (U.S. Department of Energy, 2006). Consumers can voluntarily join such programs, but after they participated in DR programs, the demand reduction is usually not an option but an obligation. There are several types of incentive-based DR programs: direct load control; ancillary services market program; demand bidding buy-back program; capacity market program; emergency demand response program; interruptible/ curailable service (ERRA, 2008).

Direct load control

The direct load control program differs from the majority of incentive-based DR programs. The special feature of this program is that participants' electric equipment is equipped with a remote switch-off device. The switch-off device gives the possibility for the system operator to control the consumers load. The participants' equipment is switched off automatically by the program operator in periods of high wholesale market prices (ERRA, 2008). The switch is activated through a radio signal. Typically the switch-off device is installed for heating appliances (Osborne & Warrier, 2007). Direct load control programs are suitable for residential or small commercial customers (ERRA, 2008).

The following two programs: the ancillary service market program and the demand bidding program can be grouped together, because both of this programs have the same feature. Both programs operate through a bidding system.

Ancillary services market program

According to the Union of the Electricity Industry (Eurelectric), the ancillary services are "…all services required by the transmission or distribution system operator to enable them to maintain the integrity and stability of the transmission or distribution system as well as power quality" (Reinhold, 2004 p.8). Participants of this DR program are only large consumers (ERRA 2008). According to this program, participants make bids into ancillary services markets to provide operating reserves

(U.S. Department of Energy, 2006; ERRA, 2008). Operating reserves are necessary to ensure, that energy is available in periods of high demand. In periods of high demand, participants of the program operate in the standby regime. It means that they are ready to diminish their consumption. If their bids are accepted, they receive a payment for being on standby. In case of load reduction they also receive a payment for load curtailments (U.S. Department of Energy, 2006).

Demand bidding/ buy-back program

The demand bidding program belongs to the newest type of incentive-based DR programs. There are two types of demand bidding programs. In the first type, the consumer bids directly on a day-ahead basis for the appropriate price and the level of reduction. So, the consumer alone decides about the ideal optimization schedule. If the consumer's bid is accepted, he should execute the earlier agreed reduction of consumption. The second type makes the consumer behave as a price-taker. He reduces his consumption when notified and receives the market-clearing price as a payment (ERRA, 2008).

The main difference between ancillary service market and demand bidding programs is that in the first program participants should reduce their consumption to a level, which is determined by the system operator, while in the second program participants alone determine the level of load reduction. The second difference is that, the ancillary services program is available only for large consumers, while in the demand bidding program participate only small- and middle-size customers.

The following three programs can also be grouped together, because the main feature of these programs is the reduction of peak consumption to a predetermined level.

Capacity-market program

Under the capacity-market program, customers should reduce their consumption to a predetermined level when the grid operator thinks that the system reliability conditions could be compromised. In return, participants receive an up-front payment. The participants have to pay penalties if they do not follow the rules of the program. This type of DR program can be compared with an insurance system, where in return for being obligated, participants get a guaranteed payment (Osborne & Warrier, 2007). The capacity-market program is common for big consumers (U.S. Department of Energy, 2006).

Emergency demand response program

Participants of the emergency DR program, receive some incentive payments if they reduce their consumption during emergency events. However, the decision is voluntary. This type of DR programs is similar to the capacity-market program. What makes this program different from the capacity-market program is that participants should not pay penalties in case of non-compliance (ERRA, 2008). Therefore, the disadvantage of emergency DR programs is that system operators cannot predict how much of load reduction will occur (Osborne & Warrier, 2007).

Interruptible/ curtailable service

As in other programs, participants of the interruptible/curtailable service should reduce their consumption to a predetermined level in case of emergency. Participants usually are informed one hour in advance. This program differs from the previous two programs, because participants who fail to reduce the consumption are removed from the program. Customers, who follow the rules, receive a bill credit (ERRA, 2008).

Alternatively to incentive-based DR programs, price-based DR programs are associated with the reduction or shifting of the consumption, when customers face wholesale prices that vary according to different supply conditions (MIT, 2011). So, in the price-based DR programs, the main trigger for changes in consumption is different prices for electricity. Prices in that case vary because they reflect the real variations in costs for the electricity generation. Price-based DR programs give the possibility for consumers to reduce their electricity bills by shifting their consumption to cheaper time periods (ERRA, 2008).

There are three price-based DR programs: time-of-use tariffs (TOU); critical peak pricing (CPP), and real time pricing (RTP). The programs differ mainly in the frequency of price changes (ERRA, 2008).

TOU program

The TOU program is the most popular program among residential customers. Under the TOU program, tariffs for electricity are predetermined and reflect the average cost for generation and delivery electricity in the given period of time. The simplest example of a TOU program is when consumers pay different prices for different seasons. A more complicated example is when consumers face a price for electricity that may vary within days.

One of the important tasks that occur during the implementation of a TOU program is the determination of price spread and number of time periods. Off-peak periods are usually weekends and weekday nights, while peak periods are weekday mornings and afternoons. The right number of time periods and corresponding prices should be elaborated in a way to reflect the wholesale market price. On the other side, the system should look simple and understandable. It should allow consumers to change their electricity consumption according to their preferences (ERRA, 2008). The price for electricity under TOU tariff reflects the fact, that the price on the wholesale market is higher during high demand. However, the TOU tariff does not purely belong to dynamic pricing. The TOU tariff generalizes prices. For example, it generalizes a price for the summer without changing on very hot summer days, when the demand for electricity is significantly higher (Faruqui & Sergici, 2010).

CPP program

Under the CPP program consumers agree to pay a pre-specified high tariff rate, in case of critical events. This high rate is typically imposed for a very small number of situations. Usually system operators choose a small numbers of days, when the expected demand for electricity is significantly higher than the available supply. On those days the price for electricity consumed in peak hours is several times higher than the usual peak rate (ERRA, 2008; U.S. Department of Energy, 2006). CPP programs are usually based on TOU tariffs or flat rate tariffs. At the time of critical events the real wholesale price is applied (Osborne & Warrier, 2007). As a reward for paying a very high price in those critical events, customers receive a discount rate for the rest of the year. As in all price-based DR programs, the participants of the CPP program are able to reduce their electricity bills by shifting their consumption from more expensive periods to less expensive (Faruqui & Sergici, 2010).

RTP program

The real-time pricing program is a pure type of dynamic pricing (Faruqui & Sergici, 2010). Under this program, the retail price for electricity varies continuously and reflects the changes in the wholesale price. Therefore, the disadvantage of this program is that the consumer might have difficulties in planning his consumption (ERRA, 2008). It is common for a RTP program to have two different price settings: “hour-ahead pricing” or “day-ahead pricing” (Faruqui & Sergici, 2010). The participants of a day-ahead pricing program receive a notice of the price for each hour of the next day. The participants of an hour-ahead pricing program receive the information about the price one hour in advance. In that case the price is based on the actual grid operating conditions. The participation in the RTP program can be obligatory or voluntary (ERRA, 2008).

The importance of dynamic tariffs for electricity is explained by the features of the electricity market, and the price formation on it.

2.2. *Features of the electricity market and the price formation on it*

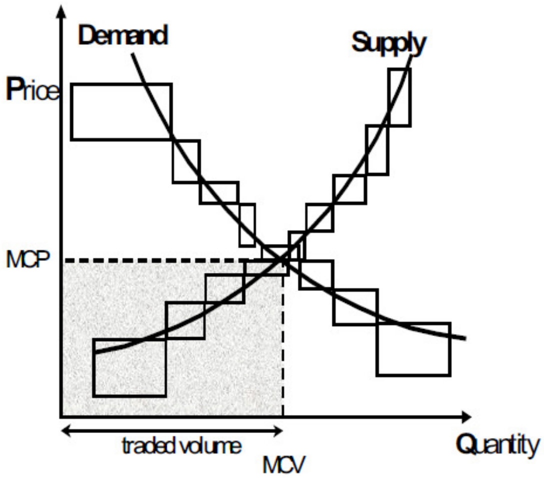
The electricity market differs from the majority of commodity markets. One of the most important features of electricity, as a commodity, is that it cannot be stored. Due to this fact, the balance between supply and demand should be done precisely at each moment of time. Nevertheless, the demand varies continuously, according to the different needs of consumers. Demand for electricity is defined as “the quantity of electricity that end-users are willing to consume at any given price” (Boisseleau, 2004 p.99). Supply on the electricity market consists of the output of all generators, used to provide the consumers’ electricity needs.

The sale of electricity occurs on two different markets: the wholesale market and the retail market (Boisvert et al. 2002).

2.2.1. Wholesale market

The wholesale electricity market is usually formed as a double-side auction. Every kWh of electricity is traded on the wholesale market for the future resale to the end-users. Typical participants of the wholesale market are: electricity producers and electricity suppliers. Electricity producers generate electricity. Electricity suppliers buy electricity from different electricity producers in order to resell it to end-consumers. Electricity suppliers make their bids for the necessary quantity of electricity, using the forecasted demand. Simultaneously, generators offer prices, for which they are able to produce that quantity of electricity. The Independent System Operator (ISO) collects aggregate bids in order to present an aggregate supply and demand curve. The intersection of those aggregate demand and supply curves determines a market clearing price and a market clearing volume for each hour (Boisseleau, 2004).

Figure 2: Price formation on the wholesale electricity market



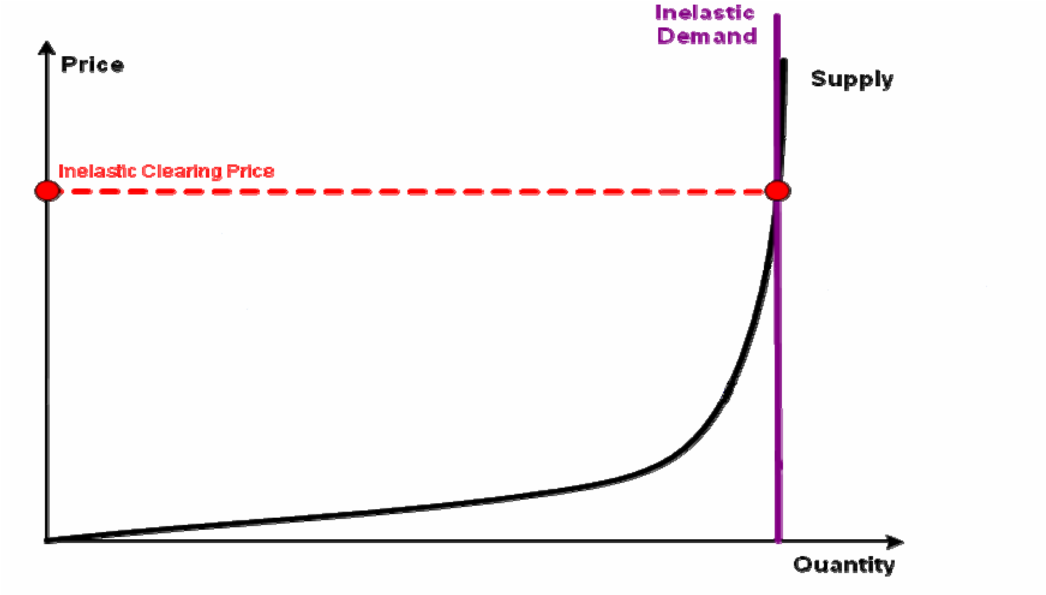
Source: Boisseleau, 2004, p.127

The price level for electricity on the wholesale market goes up in time of high demand, and decreases during low demand.

2.2.2. Retail market

Energy providers or energy suppliers balance the equality of supply and demand mainly through the supply-side tool. “A double-sided market is an institution that enables buyers and sellers to find each other and to consummate transactions for mutual benefit. A market without active bidding on the demand side, it is still only a single-side market” (Aalami et al. 2009 p.243). Commodity markets are usually organized as a double-side market, where the intersection of aggregate supply and demand creates a market price of commodity (Boisseleau, 2004). In contrast, the retail price on the electricity market is established by the equilibrium between real supply and forecasted demand. Since end-users do not participate in the price formation, graphically we can see that the demand curve is just a vertical line. The vertical demand curve reflects an inelasticity of demand. Due to the lack of consumers’ incentives to consume in a more effective way, the demand is inelastic under fixed price (IEA, 2011).

Figure 3: Price formation on the retail electricity market



Source: International Energy Agency (IEA) 2011, p.15

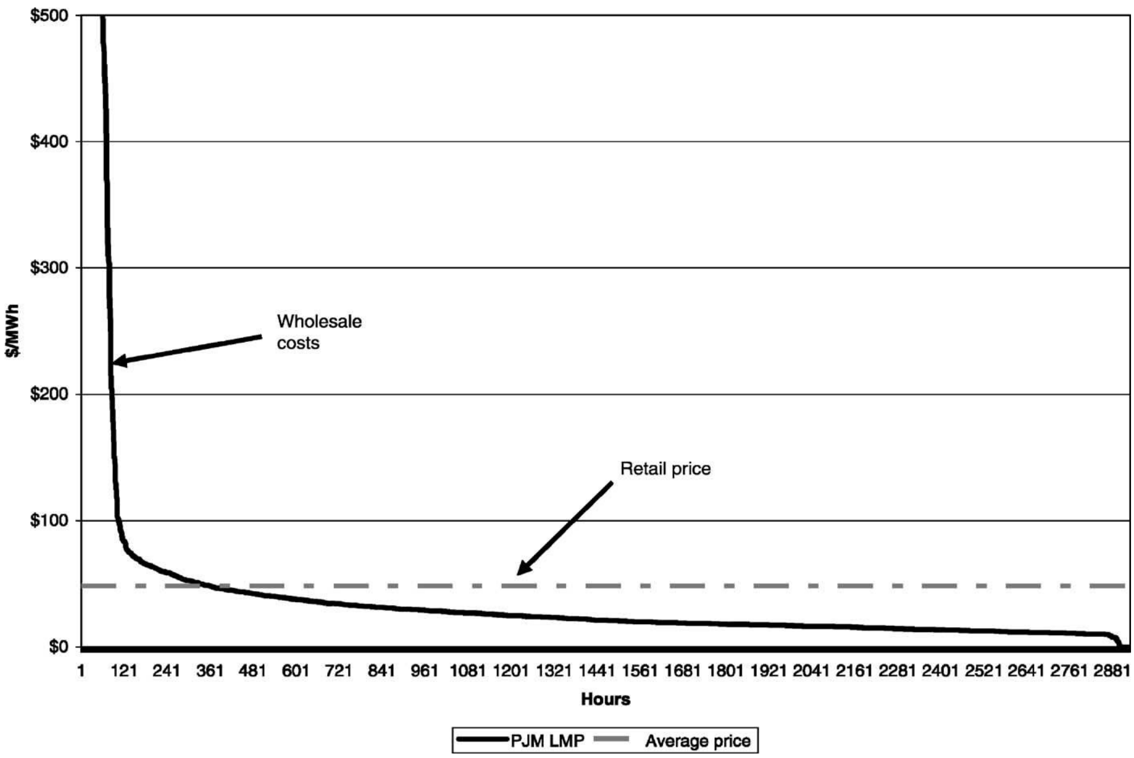
The supply curve shows the quantity of offered electricity that can be sold at any given price at any given period. The demand curve shows the forecasted demand for electricity.

The balance on the retail electricity market is usually achieved by the adjustment of the generation schedules to the forecasted demand. A lot of methods for demand forecasting are available today. The most common are: trend method, end-use method, and econometric approach. For more precise estimations, forecasters use a combination of those methods, but still there are a lot of inaccuracies. The forecast updates over the time. By using additional services, electricity providers adjust the deviation of the actual demand from the forecasted one (Meetamehra, 2002).

The inelasticity of the demand curve is an important issue in the electricity system. Inelasticity of demand represents the absence of the end-consumers' response to price changes on the wholesale market (Boisseleau, 2004). As a result, hourly wholesale electricity costs often diverge from retail prices for electricity (Braithwait, 2003).

Figure 4 represents the deviation of hourly wholesale costs from the average retail price on the US wholesale electricity market in 1999.

Figure 4: Distribution of hourly wholesale market costs vs. average retail price

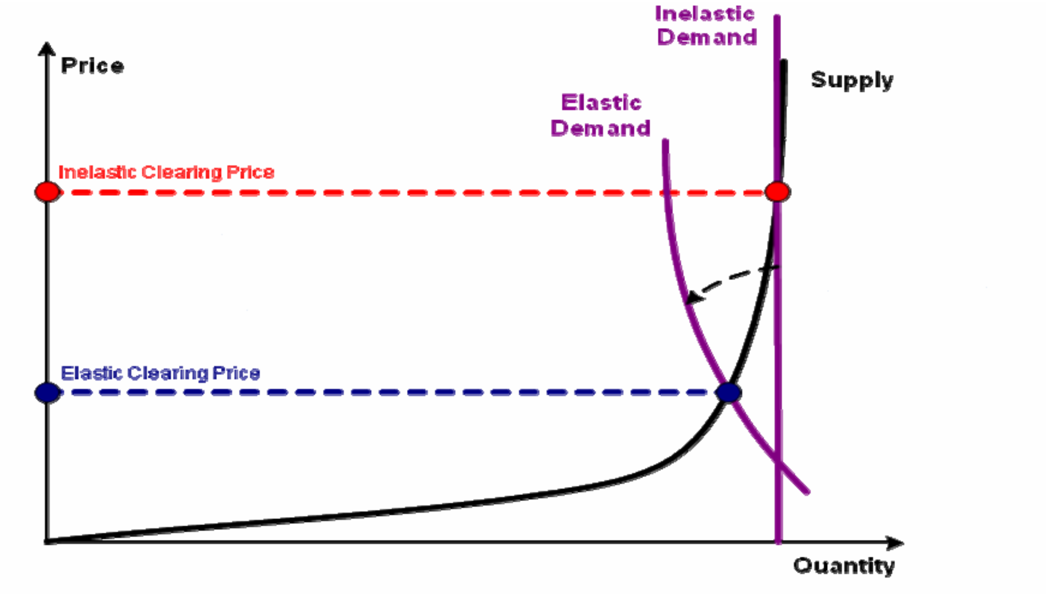


Source: Braithwait, 2003, p.53

This lack of interaction between wholesale and retail prices can be solved by introducing dynamic prices for the end customers.

Figure 5 shows how price responsive demand will change the price formation on the electricity market.

Figure 5: Demand response potential to improve market efficiency



Source: International Energy Agency (IEA) 2011, p.15

Price responsive demand creates a new equilibrium, which reflects a lowered market clearing price, and a reduced consumption level (IEA, 2011).

A reduced wholesale electricity price is not the only benefit that DR programs bring to the consumers.

2.3. *Benefits of demand response programs*

The U.S. Department of Energy (US DOE) defines three types of benefits from demand response programs: direct, collateral, and other benefits. The benefits are classified according to how wide the benefiting consumer group is (ERRA, 2008).

Table 1: Benefits of demand response programs

Type of Benefit	Recipient(s)	Benefit		Description
Direct benefits	Participants of DR programs	Financial benefits		Bill reduction
				Payment for the participation
		Reliability benefits		Reduced exposure to induced outages
				Opportunity to assist in risk reduction of outages
Collateral benefits	Some or all customers	Market impacts	Short-term	Reduction of the marginal price
				Fulfilling of short-term capacity requirements
			Long-term	Avoiding of additional capacity costs
				Avoiding of network infrastructure modernisation
				Reducing need for market interventions
		Reliability benefits		Reduced likelihood of induced outages
				Different resources available to maintain system reliability
Other benefits	Some or all consumers, Suppliers	More robust retail markets		Market-based options gives opportunities for innovations in competitive retail markets
		Improved choice		Customers and suppliers can choose desired degree of hedging
				Options for customers to manage their electricity costs, even when retail competition is prohibited
		Market performance		Elastic demand diminishes capacity for market power
				Prospective demand response deters market power
		Possible environmental benefits		Reduced emissions due to reduction in operation of peaker plants
		Energy independence		Local resources within states or regions reduce dependence on outside supply

Source: ERRA, 2008, p.20-21

Direct benefits

End-consumers obtain direct benefits. The benefits of end-consumers are divided into financial and reliability benefits (ERRA, 2008).

Consumers obtain a financial benefit by shifting their electricity consumption from more expensive to the less expensive time. The participants of incentive-based programs also receive an additional financial benefit. There are payments for the participation in incentive-based programs (U.S. Department of Energy, 2006). The overall size of financial benefits for end-customers depends on their ability to plan their consumption and shift it to “cheaper” time periods (ERRA, 2008). Demand response programs require an effective use of electricity, while the effective use implies not only to consume less, but also to arrange the consumption in time (Barreda-Tarrazona et al. 2009).

All participants of DR programs receive benefits from the increased energy supply reliability. The reduction of electricity consumption in peak time results in a stable electricity supply and excludes blackouts (U.S. Department of Energy, 2006).

Collateral benefits

Collateral benefits arise due to the impact of DR programs on electricity supply costs, and can be divided into two groups: market impacts and reliability benefits (US Department of Energy, 2006). By diminishing the ability for suppliers to raise the power prices above the production costs, demand response programs influence the general market performance. The main part of end-user’s electricity bill contains the cost for the electricity provision. The electricity provision for the end-customer usually includes some stages like: generating, transmitting, distribution and retailing. On the retailing stage the electricity supplier buys electricity on the wholesale market and this price affects the retail price.

In time of high demand the price for electricity generation can be twice higher than on valley-time. The retail price replicates the wholesale price. Because of that reason, providers raise the retail price to cover the wholesale market price. The reduction of the electricity consumption in the peak period lowers the wholesale price, and therefore diminishes the retail price. The purchase of electricity in time of shortage requires also additional costs for the transmission. DR programs lower the marginal electricity costs by diminishing costs for electricity supply (Boisvert et al. 2002). More stable prices and the limitation of uncertainty on the market create more possibilities for long-run contracts and decrease the fuel price volatility (Kannberg et al. 2003).

DR programs also create long-term market benefits by diminishing the need to build up additional power plants. The electricity market is very capital-intensive, and a decrease of the need for not necessary investments is an additional source for savings.

Benefits which come from the increased system reliability belong also to the group of collateral benefits. The active participation of end-customers on the wholesale market improves the overall energy supply. The threat of mistakes and costly adjustments in demand forecasting would be eliminated by the real-time demand. Demand response programs lower the probability of forced outages, or opposite, the necessity to purchase additional electricity. As a result, the demand for electricity becomes more predictable and the energy supply more reliable.

The reduction of the electricity demand to the potential level of the electric grid reduces the danger of full-scale blackouts (U.S. Department of Energy, 2006).

Other benefits

There are many benefits from demand response programs for economy and consumers, but the most important one is that demand response programs improve the effectiveness of the resources consumption. Electricity generation is one of the biggest polluter (IEA DRR, 2006). Implemented DR programs show that, understanding of the real electricity price turns consumers to use electricity in a more efficient way (U.S. Department of Energy, 2006). The effective electricity usage results in energy saving which has impact on the overall environmental situation. The reduction of consumption in peak time diminishes the need for additional power plant operation. This results in the reduction of emissions to the atmosphere (IEA DRR, 2006). Operated DR programs in the US show a significant reduction of the power plants' emissions in all states (Kushler et al. 2004).

Price-responsive demand makes a retail market stronger and it supports the innovations from the retail suppliers (Barbose et al. 2005).

The next important benefit is that DR programs mitigate the market power. Providers of electricity tend to have significant market power in periods of electricity shortage. In such periods providers are able to increase market prices significantly above the generation cost. By reducing the consumption in peak periods, DR programs damp the market power. This results in setting prices close to the cost of electricity generation (IEA DRR, 2006).

DR programs give the possibility for end-consumers to improve their consumption choice. Participants of DR programs are able to choose the price at which to consume (U.S. Department of Energy, 2006). Faruqui &Wood (2007) say that: "The "one size fits all" pricing concept for electricity is not economically sensible and forcing customers that are flexible and responsive to subsidize those that are not makes little sense" (Faruqui & Wood, 2007 p.39).
Due to existing possibility of risk management, DR programs also give the benefits for the suppliers of electricity. Risk management is connected with the fact that wholesale and retail prices change in a different pace. Suppliers of electricity face hourly variations of wholesale prices, and provide electricity for consumers for prices that change in a much slower pace.
Demand response provides the possibility to reduce the risk of suppliers and customers.
Retailers can diminish price risks, by creating "callable quantity options" i.e. contract for DR (IEA DRR, 2006).
In spite there are sufficient benefits from DR programs, there is a range of barriers that deters the promotion of DR programs to the mass.

2.4. ***Barriers and the cost of demand response programs***

The U.S. GAO (U.S. Government Accountability Office) determines three important barriers to provide DR programs to the mass: the government energy policy that protects people from price fluctuation; deficiency of the required equipment; the limited knowledge of consumers about benefits of DR programs (GAO, 2004).
Basically, all barriers to implement DR programs into the energy market can be divided into: barriers for government; barriers for customers.

2.4.1. Barriers for government

An important barrier that deters the introduction of DR programs to the mass comes from the government regulation. There are many utility companies that would have loss due to the implementation of DR programs to the mass. Utilities are public organizations, which provide water, electricity, and communications to the public. Utility companies benefit from electricity selling. Their revenue is proportional to the quantity of sold electricity (FERC, 2010). As DR programs require the reduction in consumption, it could result in the revenue reduction for those companies (ERRA, 2008; Kushler et al. 2004; Faruqui & Wood, 2008). Under such a structure of the electricity market, utility companies have no incentives to promote DR programs to the mass. Therefore, revenue losses of utilities caused by the implementation of

DR programs should be insured by regulatory mechanisms (Kushler et al. 2006). The possible solution for this problem would be to establish a policy system that would separate dependence of profit from the quantity of sold electricity (ERRA, 2008). One way to make it possible would be to compensate losses of utility companies, by providing a rate of return from the increased level of investments in the electricity market (Kushler et al. 2006). However, without well-organized regulatory mechanisms, investments in the electricity market will be low, even if such programs help to save resources (Vine et al. 2003). In order to avoid a variability of regulatory standards, the compensation procedure should be unified for all utility companies (Reilly, 2003).

In order to overcome regulatory barriers, FERC (Federal Energy Regulatory Commission of U.S.) proposes the following activities: to reform the state policy in order to diminish a negative effect from DR programs on utility companies; to reform the wholesale market structure in order to simplify the process of end-users participation; to improve the cost-effectiveness of DR programs (FERC, 2010).

To overcome regulatory barriers, Markard & Truffer (2006) also underline the importance of electricity market modernization. However, they believe that innovations on such a “large technical system”, as an electricity supply can be more incremental than radical (Markard & Truffer, 2006 p.609). The authors are convinced that, an electricity supply system consists of a big variety of components that are strongly interrelated and interdependent. Due to this fact, the innovations can be complicated. Changing or removing one element of a system may result in the necessity to modify the whole system, for which the government could be not prepared. An innovation on the electricity system should satisfy needs of consumers, as well as to correspond to the “existing infrastructure” (Markard & Truffer, 2006 p.611).

Another barrier that deters the implementation of DR programs is high costs of those programs. Costs of DR programs have two different levels: costs of participants and system-wide costs (ERRA, 2008). The government bears system-wide costs that consist of initial and ongoing expenses.

Table 2: System-wide costs of demand response programs

Type of Cost		Cost	Responsibility/ Recovery Mechanism
System costs	Initial costs	Modernization of the metering system	Cost level and cost responsibility varies according to the scale of the modernization (e.g., large customers vs. mass market). State policy should be improved to provide DR programs to the mass market.
		Utility equipment or software costs, billing system modernization	Public benefits funds
		Customer education	Ratepayers, public benefits funds
	Ongoing program costs	Program management	Costs bear administering utility, and it recovers from ratepayers
		Recruitment	
		Payments for participation	
		Program evaluation	
		Metering	

Source: U.S. Department of Energy, 2006, p.23

Costs for the modernization of the utility billing system belong to the initial government expenses. Many utility companies do not have the necessary equipment to handle time-varying costs (U.S. Department of Energy, 2006).

An important part of initial government costs is expenses for customer education. In order to implement DR programs, consumers should be aware of the possibilities to reduce their electricity bills. It means that, implementation of DR programs requires an additional outlay of the capital. Participants of the majority of DR programs should be equipped with advanced meter systems that measure the electricity consumption in intervals (U.S. Department of Energy, 2006). Therefore, it requires employing more people who will be responsible for the installation activities. As a result, the initial costs for providing dynamic tariffs increase, when the size of consumers decreases. Therefore, many system operators could be not interested in providing DR programs for small- and middle-size consumers (ERRA, 2008). An improvement of the cost-effectiveness could increase the participation in DR programs. However, it is a challenge to develop strategies in a way that would diminish initial costs, and would attract the mass market (Reilly, 2003).

To the ongoing costs belong expenses for the program management, program evaluation, and payments for participants. Program management and evaluation includes costs for setting up the DR strategy and testing this strategy on experiments and so on. Payment for participants exists only for incentive-based DR programs. Therefore, providers of price-based DR programs have almost no ongoing costs (U.S. Department of Energy, 2006).

2.4.2. Barriers for customers

One of the barriers that deter participation of end-consumers in DR programs is the lack of information about their priorities and disadvantages. The majority of end-consumers are just used to a fixed price for one kWh of electricity. Compared to a fixed price, dynamic pricing is more complicate. Therefore, without providing enough information and detailed explanations, participants will not fully understand the advantages of DR programs. Participants could be confronted with difficulties from the beginning. At the beginning, consumers need to choose the appropriate DR program. DR programs should be chosen individually for each consumer. A program which is profitable for one consumer might not bring benefits to the other ones. It depends on the consumer's life style, his ability to reduce or shift consumption in time and other factors. For example, some consumers could reduce their electricity bill by switching on the washing machine for two hours later, but it could be absolutely not possible for the other customers (ERRA, 2008; FERC, 2009). Unfortunately, DR programs do not always lead to a reduction of electricity bills. In case of inappropriate choice of the DR program, electricity costs could increase (King & Delurey, 2005). Some problems could occur due to miscalculations. Some participants could multiply costs and decrease or underestimate benefits, and therefore these programs could find not enough response from the consumers (ERRA, 2008).

Researches show that many potential small- and middle-size customers do not participate in DR programs due to the threat of price risks. Since the price varies hourly, customers may conclude that electricity bill savings are insignificant compared to the risk of high price instability. To attract potential customers, providers should offer nice risk-reward proposals that would keep price-based DR programs more attractive than the fixed-price rate (Goldman et al. 2006).

In order to come over the mentioned barriers and to increase the participation in DR programs, FERC of the U.S. recommends the implementation of consumer education. The concept of education should include explanations about benefits of DR programs and the consumer ability to control his consumption, as well as explanations about further possibilities e.g. environmental improvements (FERC, 2009). This campaign should be done not just to increase the percentage of participation, but also to cover some re-training for the already existing participants. If the price remains on a low level for a long time period, participants of DR programs may tend to forget about price variations, and could start to consume in a less effective way (Goldman, 2006).

Another crucial barrier for consumers might be the investment in DR programs.

Table 3: Costs of DR programs for the participants

Type of Cost		**Cost**	**Responsibility/ Recovery Mechanism**
Participant costs	Initial costs	Investments in technologies	Customer pays; incentives to offset portion of cost may be available from public utility
		Establishing response plan or strategy	Customer pays; technical assistance may be available from public utilities
	Ongoing costs	Comfort/inconvenience costs	Customer bears “opportunity costs” of foregone electricity use
		lost business	
		Rescheduling costs (e.g., overtime pay)	
		Onsite generator fuel and maintenance costs	

Source: U.S. Department of Energy, 2006, p.23

Each participant who joins the program has to make initial investments. Moreover, he faces ongoing costs during each load reduction act. To the initial costs belong investments in necessary technologies, and cost for personal assistance in order to choose the most appropriate DR program. The necessary equipment includes “smart” meters, in-house displays, and communication systems. Investments in the equipment can be quite costly for small and medium consumers; therefore, it could diminish the penetration of DR programs to this customer segment. In order to avoid the problem of initial investments and not to lose small- and middle-size customers, the providers of DR programs should provide long-term credits for those customers segments (ERRA, 2008; U.S. Department of Energy, 2006). In 2010 U.S. FERC proposed to reconsider in general the issue of who should bear the initial cost. As we have seen, the benefits of DR programs spread not only for the participants of DR programs, but also for all electricity consumers. DR programs improve the environmental situation, as well as diminish overall costs for electricity supply (Boisvert et al 2002). However, the initial costs bear only participants of DR programs. Passing all costs only to the participants could reduce their willingness to participate (Faruqui &Wood, 2008). Goldman (2006) has proposed a solution for the fundamental policy. He recommends dividing of all costs between participants, and those who receive any benefits from DR programs. However, the benefits of non-participants are still not well understood (Goldman, 2006).

The ongoing costs of participants can be divided into: calculable, and abstract. Abstract costs are associated with the discomfort, due to the limitation or shifting of the electricity consumption. The ongoing cost can be also more measurable. Calculable ongoing costs could be costs for the loss of business activity. The ongoing cost can be just individually determined (ERRA, 2008; U.S. Department of Energy, 2006).

However, investments in necessary equipment i.e. advanced metering infrastructure remain one of the greatest barrier that deters the participation of end-consumers in DR programs (FERC, 2010).

2.5. ***Advanced metering infrastructure***

A typical advanced metering infrastructure (AMI) consists of: a metering device, “smart” meter; a graphical display, or in-house display (IHD); a communication system (Balmert et al. 2012).

Smart meters

The role of traditional meters is to measure the electricity consumption over a long period of time (IEA, 2003). There are visible advantages of the old meters: low installation cost and low maintenance cost (Batlle & Rodilla, 2009). Traditional meters report the quantity of overall consumed electricity by end-users, from the time of the last meter reading. In order to determine the monthly electricity bill, a consumer who pays a flat rate, needs to know the quantity of the total monthly electricity consumption. In contrast under dynamic tariffs, the price for electricity varies hourly; therefore, consumers need to be equipped with technologies that provide information about price variations. One of those technologies is a smart meter, or advanced meter (IEA, 2003). FERC gives the following definition of advanced meters: “Meters that measure and record usage data at hourly intervals or more frequently, and provide usage data to both consumers and energy companies at least once daily. Data are used for billing and other purposes. Advanced meters include basic hourly interval meters, meters with one-way communication, and real time meters with built-in two-way communication capable of recording and transmitting instantaneous data” (FERC, 2010 p.6). Smart meters give the possibility to record data in a timed interval - typically in 15, 30 or 60 minutes (IEA, 2003).

In-house displays

An in-house display is a graphical display, connected to a smart meter and a communication device. It shows the quantity of the actual consumption and provides information about the consumption of previous periods. An in-house display is not a necessary part of the advanced metering infrastructure (Balmert et al. 2012). However, the group of experiments done by Brattle Group show that, additional technologies, as in-house display sufficiently improve customer's response to price signals (Faruqui & Sergici, 2010).

Communication system

A communication system provides the possibility to exchange data between consumers and utilities. The communication system is based on communication technologies such as: wireless, power line communication (PLC) or the Internet Protocol (IP) (Balmert, 2012). The most common communication system is the Internet. It gives the possibility to arrange the communication between utilities and end-users in real-time (IEA, 2003).

The most costly part of the advanced metering infrastructure is the smart meter. Costs for smart meters vary among countries. The overall costs depend on the functionalities and technical features of smart meters. The more technical features it will have, the higher the final costs. Next to the purchase price the cost for installation and maintenance is a major part. It is difficult to provide average expenses, because the meter's price and requirements vary in each country (Altmann et al. 2012). However, the International Energy Agency gives the price comparison between basic and advanced meters (IEA, 2003).

Table 4: Purchasing and installation costs for the basic and advanced meter

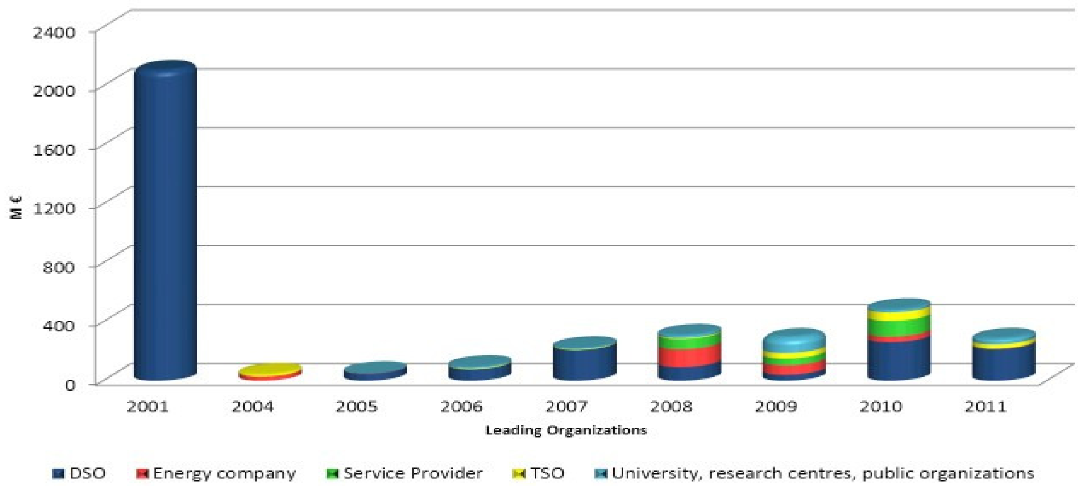
	Replacement		Mass Deployment	
	Residential	Industrial	Residential	Industrial
Basic Meter	$20-25	$150-200	$15-20	$100-150
Advanced Meter	$80-100	$175-200	$30-55	$150-175
Meter Installation	$50	$150	$25	$100

Source: International Energy Agency (IEA), 2003, p.125

The deployment of an advanced metering system is one of the important steps that need to be done to implement DR programs to the mass market (ERRA, 2008).

The EPRI (Electric Power Research Institute) in 2011 estimated the impact of the main leading investing organizations, on the deployment of smart meters in Europe. The investing organisations were grouped in the following groups: energy companies; Distribution System Operators (DSO); Transmission System Operators (TSO); service providers; research centres (JRC, 2011).

Figure 6: Investments in smart meters among leading organizations



Source: Joint research center (JRC) 2011, p.24

The results show that overall in Europe the majority of investments have been done by the Distribution System Operators (DSO). DSO organisations are organisations that ensure the continuous work of the low-voltage energy grid (Altmann et al. 2012). The highest investments for the deployment of smart meters in Europe were done in 2001. This is explained by the national roll-out of smart meters in Italy (JRC, 2011). Italy was the first country in the EU which introduced a smart metering system when there was no regulatory framework for it. The motivation for it was the reduction of non-technical losses, i.e. fraud. In 2001, 85 % of the Italian population was equipped with smart meters. Now, the installation of smart meters is almost completed (Balmert et al. 2012).

The deployment of smart meters within Europe is uneven. It is explained by the different energy policies. According to ESMA 2010 (European Securities and Markets Authority) there are two countries which completed the roll-out of smart meters. It is Italy and Sweden. In Finland the installation process should be finished by the end of 2014 (Altmann et al. 2012). Due to the low level of advanced metering deployment, the number of operating DR programs is not high all over the world. However this amount continuously increases (Balmert et al. 2012; ERRA, 2008).

2.6. *Experience with demand response programs*

The absolute leader, in the number of operating DR programs in the world is the U.S. According to the FERC 2010, there are more than 500 institutions in the United States that provide DR programs. The biggest part of existing and operating DR programs in the U.S. belongs to load management programs. More than half of the national peak load reduction in the U.S. is provided by those programs. To the emergency programs belongs 25 % of the whole national peak load reduction potential (FERC, 2010). However, since emergency programs are voluntary for customers, they do not provide a necessary degree of certainty in the load reduction. Due to that reason DLC (Direct Load Control) programs and interruptible services are prioritized for the grid operator. Therefore, the second largest category belongs to the interruptible/curtailable services. These programs are orientated for large customers (MIT, 2011). Nearly 20% of the national peak load reduction of the U.S. belongs to interruptible services. The first place, according to the number of participants, belongs to direct load control programs. However, those programs take the third place in the quantity of peak load reduction. To direct load control programs belong 17 % of the total load reductions. Insignificance in the amount of the peak load reduction is explained by their design. DLC programs were designed to operate in case of danger to the reliability of the electricity supply. Therefore, they are not frequently executed (FERC, 2010; MIT, 2011).

Price-based DR programs did not become so popular in the US. According to the FERC 2010, only 8% of the national peaks load reduction was achieved by price-based DR programs. The most popular price-based program in the U.S. is the TOU (time-of-use). This program became quite popular among all consumer types. A TOU program gives the possibility to view a price profile far in advance. Usually prices hold constant over the season. Therefore, consumers do not need to plan their electricity usage for every hour. In contrast, real time pricing and critical peak pricing programs, where prices vary hourly did not become so popular. The price variation is not the only inconvenience for the customers. These programs require significant initial investments; therefore those programs did not find enough response from small- and middle-size customers (FERC, 2010; MIT, 2011).

The popularity of DR programs in Europe is not so high. The main barriers that deter introduction of DR programs to the European electricity market are: "limited knowledge on DR energy saving capacities; high cost for DR technologies and infrastructures; low level of liberalization of EU market" (Torriti et al. 2009 p.1). The European parliament and Maastricht (1993) try to force a liberalization process by the separation of two actions: supply and sales of electricity (Boisseleau, 2004; COM, 2006). The European power market today is a combination of independent regional markets. The regulation policies and technical standards are different in all countries. In contrast, the liberalization process will lead to a creation of a single Internal Electricity Market (IEM), where technical standards and price policies are unified. It will create appropriate conditions for the implementation of DR programs (Torriti et al. 2009).

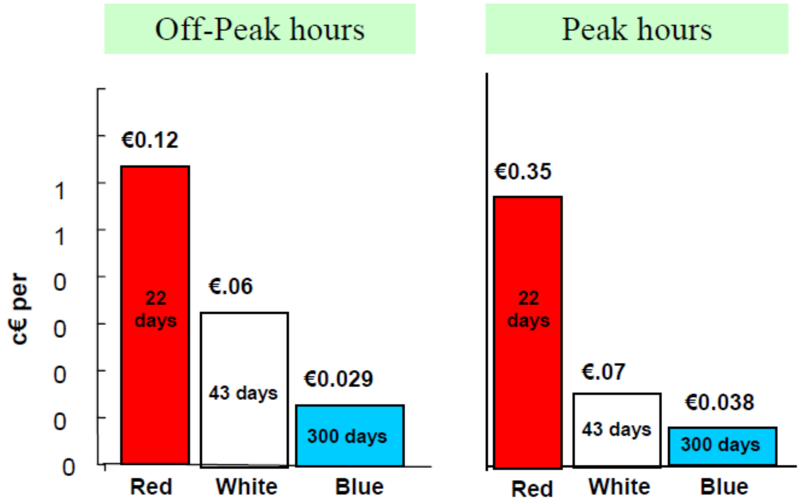
Due to existing barriers in the European countries, it is rather realistic to talk about DR potential than about a success of DR programs. All European countries can be divided into those which have at least a small level of operating DR programs and those which do not even consider DR in their network planning. DR programs in Europe are mainly used by large energy consumers, therefore interruptible programs are prevailing. These programs are less costly to adopt and based on a price discount for the interruption in consumption (Torriti et al. 2009). To increase the participation of small- and middle-size customers the government energy regulatory policy should be improved. There are two directives in the EU which are addressed to DR programs. The first directive is addressed to improve the energy-use efficiency, but it does not imply DR options directly: "In defining energy efficiency improvement measures, account should be taken of efficiency gains obtained through the widespread use of cost-effective technological innovations" (Directive 2005/89/EC). The second directive is directly addressed to the introduction of price-based DR programs. It forces a Member State for "the adoption of real-time demand management technologies such as advanced metering system" (COM, 2006). However, there is no law in Europe that requires a mandatory participation of small- and middle- size customers in DR programs (Balmert et al. 2012).

The culture barrier is the other reason that could explain a low level of participation in DR programs all over Europe. The majority of European countries views DR as an effective tool for the peak load reduction, but do not see it as a solution for improving the environmental situation (Torriti et al. 2009).

Papagiannis et al. (2008) have estimated potential benefits of DR programs to the EU countries. They have found out that in case of high participation in DR programs, the EU-15 would reduce their primary energy consumption by 1-4%; emissions would be reduced by 1,5-5% and savings in investment cost would increase up to 8% (Papagiannis et al. 2008).

Among European countries, France has the highest number of residential participants in price-based DR programs. Since the 1960s, Electricite de France has moved to a real time pricing for electricity. "Tempo" tariff that operates in France divides a year for three types of days: 22 "red" days- the most expensive ones; 43 "white" days- with a medium price level for electricity; 300 “blue” days with a low price. In addition tariffs differ in: off-peak and high-peak. The color of the next day is determined by forecasting the demand for that day. The demand for electricity mainly depends on weather conditions. The price for “white” days is roughly the same as a flat rate. The price for “blue” days is approximately half of the flat tariff. The price on “red” days is usually five times higher than the flat tariff (Faruqui & Sergici, 2009).

Figure 7: "Tempo" tariff (France, EU)



Source: Institute for Energy Engineering, 2007

Hungary is one of the European countries with a significantly low income per capita, where the popularity of DR programs is high among residential households. Incentive-based and price-based DR programs are equally used among households. The most popular incentive-based program is “ripple control”. Ripple control is a kind of direct load control program, where participants’ appliances are switched-off automatically during times of electricity supply shortage. Participants of the ripple control program are equipped with a receiver device that allows public utilities automatically to shut-off consumers’ appliances. Under this program only a certain appliances are eligible to be served (Dan et al. 2009).

Overall there is a shortage of DR programs on European retail markets. It can be explained by: high cost of AMI technologies; the peak periods, which were used in pilot sessions, were “too broad to garner customer acceptance” (Faruqui & Sergici, 2009 p.7); the low level of incentives from utility companies; low level of consumers knowledge. Many customers even do not know about such rates (Faruqui & Sergici, 2009).

3. Literature and experiments overview

The experimental literature that studies residential demand response on an electricity market can be divided into two types: literature based on field experiments and literature based on laboratory experiments.

The earliest paper that describes a field experiment made on the electricity market was written by Battalio et al. (1979). In the experiment participated randomly chosen single families of College station, Texas (USA). The target of the experiment was to determine the impact of various price and non-price policies on the residential electricity consumption. All participants were divided into five groups: high rebate price group; low rebate price group; feedback group; information group; control group. It was proposed for all participants to reduce the average level of their peak load. In case of compliance, participants of the first two groups were receiving high or low rebates, for each reduced kWh of electricity. The feedback and information groups were designed to analyze the effect of non-price policies on the reduction of the electricity consumption. As the members of the first two groups, participants of the feedback group were asked to reduce their load during peak hours, but they did not receive any rebate. Participants of the information group received a recommendation for effective electricity usage, and did not get any rebate as well. The experiment has shown that a price policy has a higher impact on the electricity consumption than informational policies. The rebate groups have used 11-12% less electricity, than the informational group (Battalio et al. 1979). Therefore, based on the results obtained by Battalio et al. (1979), the further group of experiments was carried out to identify which price policy has the biggest impact on the peak load reduction.

A significant work to analyze the relation between the price policy design and a households' response was done by the U.S. Department of Energy. This work includes 17 pricing experiments, which were executed from 1975 to 2007 (Faruqui & Sergici, 2008). Based on their purposes, the experiments can be grouped in several groups.

The first group of experiments had the purpose to determine the peak load reduction from the TOU tariff. The first experiment from this group is the "Tempo" program that was carried out in France. The "Tempo" program is the first experiment which was executed on the European electricity market. The "Tempo" program is designed on the basis of a TOU tariff.

1. France- Electricite de France (EDF) Tempo Program.

France was one of the first countries in Europe which introduced dynamic price programs for residential households. The “Tempo” program was established in 1996. Ahead of introducing the „Tempo tariff” to the residential market, Electricite de France (EDF) organized a range of experiments in order to determine the level of customers’ satisfaction. 800 people from different regions of France have participated on those experiments. The experiments have showed that the average consumption was reduced by 15% on “white days”, where the price was on medium level, and by 45 % on “red days”, where the price was the highest. The experiments showed a strong variation in consumption behavior, even among those consumers, who had the same electric appliances. 84% of the participants have been satisfied with the program. 59 % of the participants said that they achieved savings.

2. New South Wales-Energy Australia’s Network Tariff Reform

It was the largest TOU pricing program done by (EA) Energy Australia. The purpose of the New South Wales program was to test the impact of seasonal price variations on the peak demand reduction. Prices in the experiment varied within seasons, as well as within time zones. In the experiment two different price rates were presented: a high price rate and medium rate. The results of the experiment show that residential customers under TOU rate have a higher level of conservation than residential customers under a flat rate. The conservation effect was higher for winter than for summer. The consumer’s response was higher under higher tariff rate. Customers reduced their peak consumption by 24 percent for the high rate and roughly by 20 percent for the medium rate (Faruqui & Sergici, 2008).

3. Seattle Suburbs-Puget Sound Energy (PSE) TOU program

PSE organized a TOU program for its residential and small commercial customers in 2001. Days were divided into four time zones. The price was the highest during mornings and evenings. The participants had the opportunity to go back to the flat rate if they were not satisfied with the program. The peak price under TOU rate was roughly 15 percent higher than the flat rate. The off-peak price was 15 percent lower than the flat rate. The pilot ended in 2002. In the first year of the pilot participants were not charged for meter reading. In 2002 participants were charged 1$ monthly for meter reading. The results of the experiment show that 94 % of participants of the second year paid 0, 80$ extra, compared to what they would pay under a flat rate. 55 % of participants of the first year, where meter reading costs were not charged, achieved bill savings.

The results of this group of experiments show that TOU is an effective tool to reduce the peak electricity load. The rate of peak load reduction varied between the different rate designs. The consumers' response to dynamic tariffs is higher, when the price for electricity is high.

The second group of experiments had the purpose to determine the peak load reduction from two dynamic tariffs: TOU and CPP. Some experiments from this group were designed to analyze the peak load reduction from the combination of these two tariffs. One of the earliest experiments from this group is the Gulf Power program.

4. Florida- The Gulf Power Select Program

The Gulf Power program took place in 2000 in California. The purpose of the experiment was to determine the impact of two dynamic tariffs on the residential peak load reduction. Randomly chosen participants of that experiment were provided with three service options: the standard residential service (RS) pricing option. It is a standard flat rate, without any variations in time; a conventional TOU pricing option (RST). It is a two-period TOU tariff; the residential service variable price (RSVP). It is a three-period CPP tariff.

Gulf Power reports that RSVP had the greatest impact on consumers. The participants of the RSVP program reduced the energy consumption during critical peak periods by 41 % (Faruqui & Sergici, 2008).

5. California-Statewide Pricing Pilot (SPP)

This experiment was conducted by California's utilities and ran from July 2003 to December 2004. SPP tested the following tariffs: the TOU rate, where the electricity price at peak time was twice times higher than the off-peak price; the CPP rate, where at critical days the price was five times higher than the off-peak price. On non-critical days, the TOU rate was applied. The result of the experiment showed that the CPP tariff has a greater impact (about 25 %) on the peak reduction compared to the TOU tariff (5, 9 %) (Charles River Associate, 2005).

6. Idaho Residential Pilot Program

The Idaho residential pilot program included two pilot programs: Time-of-day (TOD) and Energy Watch (EW) that took place in summer 2005 and summer 2006.

The TOD pilot was designed as a TOU program, where subjects were charged a different price at on-peak, mid-peak and off-peak time. The results from the TOD pilot show that TOD rates had no effect on shifting of the electricity consumption. The percentage of energy usage at peak time was around 22 % for both control and treatment groups.
The Energy Watch pilot was designed as a CPP program, where participants faced CPP events on a day-ahead basis. The experiment showed, that the average hourly demand reduction varied in a range from 0, 64 kWh to 1, 70 kWh.

7. Ontario/Canada-Ontario Energy Board Smart Price Pilot

The pilot was designed to test the impact of different price structures on the residential peak load reduction. Three different tariffs were tested: the existing Regulated Price Plan (RPP) TOU; RPP TOU rates with a CPP component (TOU CPP); RPP TOU rate with a critical peak rebate (TOU CPR) (Faruqui & Sergici, 2008). The CPR rate is a tariff where participants remain on their flat rate, but receive a rebate for each kWh, that was reduced during critical events (Faruqui & Sergici, 2010). In the current experiment a TOU CPR rate was used. Therefore, participants remained on the TOU tariff, but received a cash rebate for each kWh they reduced in time of critical events.
The results of the experiment show that load shifting during critical events was between 5, 7 and 25, 4 percent. The percentage of the load reduction for the TOU customers was statistically insignificant. The total reduction from the participants of TOU-CPP amounted in 4, 7 percent. The total reduction of the participants from the TOU-CPR program was the highest and amounted in 7, 4 % (Faruqui & Sergici, 2008).

8. California-Anaheim Critical Peak Pricing Experiment

The experiment took place in California between June and October 2005. 123 randomly chosen customers of Anaheim Public Utilities (APU) were divided into two groups: control and treatment group. The purpose of the experiment was to test the impact of a critical peak pricing (CPP) tariff on the reduction of the peak electricity consumption. The experiment showed that the treatment group used for 12 percent less electricity during peak hours than the control group did. The demand response of the treatment customers was higher on higher temperature CPP days than on lower temperature CPP days (Wolak, 2006).
The results from this group of experiments suggest, that consumers respond to dynamic tariffs for electricity. The rate of the peak load reduction varies between the experiments. However, all

experiments showed that the CPP tariff has the highest impact on the reduction of peak consumption. Under the CPP tariff, the peak consumption was diminished by 13-20 percent, while under TOU tariff, the peak load reduction amounted in 3-6 percent (Faruqui & Sergici, 2008).

The third group of experiments was done in the United States to estimate the importance of enabling technologies for the residential peak load reduction. One of the first experiments that were done on that direction is GPU pilot.

9. New Jersey-GPU Pilot

The pilot ran in 1997 and offered customers a TOU tariff with a critical peak price and enabling technology. The treatment customers were equipped with communication equipment that allowed them to receive price signals from the utility. The feature of this experiment was that the treatment group was divided into those who face a low tariff, and those who face a higher tariff rate. The results of the GPU pilot experiment showed that, on non-critical days the treatment group reduced their peak load by 26 percent. The treatment group that faced a higher tariff rate reduced their peak consumption by 50 percent more than the group with the lower tariff. On critical days the average peak load reduction of the treatment group was 50 percent (Faruqui & Sergici, 2008).

10. Colorado- Xcel Energy TOU Pilot

The Xcel pilot program was initiated to test the impact of TOU and CPP rates, as well as a combination of these two tariffs and enabling technologies, on demand reduction in the Denver metropolitan area. 2900 residential customers have participated in this pilot. All participants were equipped with Advanced Meters (AM). The results of the experiment suggest that a combination of TOU and CPP with enabling technologies has the greatest impact on demand reduction in peak hours (54, 22%), while TOU has the lowest effect (5, 19%).

11. Missouri-AmerenUE Critical Peak Pricing Pilot

The pilot experiment evaluated three different programs: TOU with peak, mid-peak, and off-peak rates; TOU with CPP; TOU with CPP and an enabling technology (smart thermostat). The results of the experiment show that participants from TOU and TOU-CPP group did not shift significant amounts of their load from the peak to the off-peak or mid-peak periods.

However, compared to the control group, the participants from TOU-CPP group who were equipped with enabling technologies, reduced their demand by 35 percent (Faruqui & Sergici, 2008).

12. California- Automated Demand Response System Pilot (ADRS)

The experiment was initiated by several energy companies and took place in California in 2004-2005. The participants of the pilot were equipped with a Good Watts system. It is an advanced home climate control system that allows users' to program the operation time of their home appliances according to their preferences. Consumers were observing a real electricity price and were able to program an automated reduction of their consumption in the period of high-prices. Prices were higher during peak periods (2 p.m. to 7 p.m. on weekdays). The results show that the treatment group has achieved a substantial load reduction. The enabling technology was the main driver of the load reduction. During event days the rate of peak load reduction varied between 43 and 51 percent. During non-event days the peak load reduction varied from 27 to 32 percent (Rocky Mountains Institute, 2006).

13. New Jersey- PSE&G Residential Pilot Program

This program was offered to residential customers from New Jersey during 2006-2007. The PSE&G pilot had two sub-programs. Participants of the first program, *my Power Sense*, had the possibility to choose between TOU and CPP tariff and were informed about features of this two price systems. Participants who preferred a CPP tariff were notified about the CPP events on a day-ahead basis. Under the second sub-program, *my Power Connection,* participants were equipped with thermostats that received price signals, and as in the previous program participants were able to choose between TOU and CPP tariff. Participants of both sub-programs were randomly divided for two groups and did not have the opportunity to choose the treatment they prefer more.

The result shows that, the participants of the second program reduced their peak demand by 21 percent under TOU tariff, and by 26 percent under CPP. Participants of the first program reduced their peak demand by 3 percent under TOU tariff and by 17 percent under CPP tariff. The participants of the Power Connection program reduced their peak-demand more than the participants of the Power Sense program. The larger reduction of *my Power Connection* is explained by the usage of enabling technologies.

The result of experiments from this group shows that the presence of enabling technologies increases customers' response to dynamic prices. As in the previous group of experiments the

CPP tariff has the highest impact on the peak load reduction. Customers with enabling technologies reduce their peak consumption in a range from 27 to 44 percent (Faruqui & Sergici, 2008).

The next group of experiments, which were carried out in Illinois, has estimated the residential demand response under RTP tariff. Since experiments from this group had different purposes, the rate of peak load reduction is not defined in the majority of those experiments.

14. Illinois- Energy Smart Pricing Plan (ESPP)

ESPP was the first program in the US, designed to test the impact of real-time pricing (RTP) on the peak demand reduction. ESPP was orientated for low cost technologies. Therefore, the main target of this experiment was to get benefits of RTP without adoption of expensive technologies. The experiment ran from 2005 to 2006. The result from 2005 showed that at the day with the highest price, participants reduced their peak consumption by 15 percent compared to what they would consume under the flat rate. The result from 2006 supports the finding from 2005. Moreover, participants of ESPP consumed 16, 7 kWh less per month, compared to individuals on the flat rate. During the summer month, participants consumed in addition 10, 0 kWh less electricity per month. On the whole ESPP resulted in a reduction of the monthly energy consumption (Faruqui & Sergici, 2008).

15. Illinois- Power Smart Pricing Program

The program took place in Illinois in 2007 and as the previous program, it was designed to test the impact of real time pricing on peak load reduction. Prices for energy varied from hour to hour and from day to day. The hypothesis of this experiment was that the participants would reduce their consumption in periods of high prices. The Power Smart Pricing program was not actively marketed. Therefore, only a small number of participants were enrolled. Nevertheless, the participants reduced their consumption in periods of high prices and saved on average 16, 2 percent compared to what their bill would have been on the fixed rate. The peak load reduction rate was 20% (CNT Energy, 2008).

16. Illinois-ComEd Residential Real- Time Program

The electricity tariff at this program was based on wholesale prices that varied hourly. The participants were equipped with smart meters. It allowed consumers to observe real time rates.

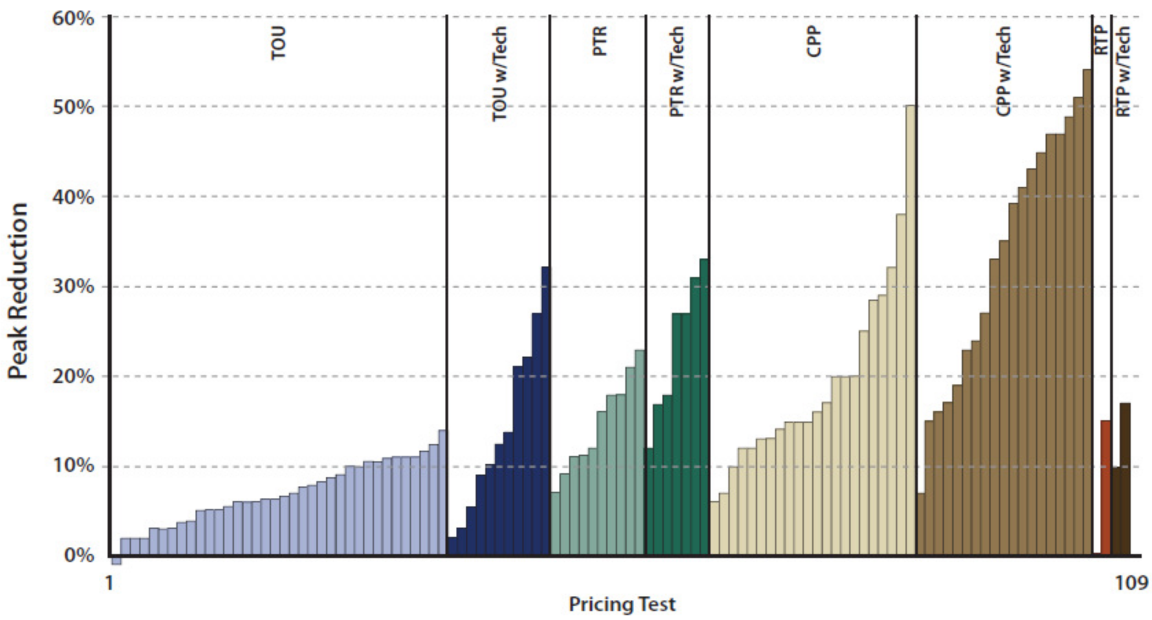
Since the purpose of the experiment was to investigate participants' bill savings under current price fluctuation, the published results of the program did not specify detailed demand response effects. The results from participants' data show that participants were benefiting from the program. 95 percent of the participants saved money, compared to what they would need to pay under a flat rate. Those participants, who had been in the program for a full year saved from 7 to 12 percent on their electricity bill.

17. Washington- The Olympic Peninsula Project

The purpose of the Peninsula Project was to test whether two-way communication systems between grid and end users are effective for the reduction of blackouts.
Participants of this program were equipped with a two-way communicator. It gave the possibility for the utilities to send market price signals to the customer. Based on the received signals consumers were able to adjust their consumption. Participants were divided into three treatment groups, with three different price systems: fixed price, where the price remained constant all the time; TOU, where the price varied between peak and off-peak time; real time pricing, where the price was unpredictable and varied every five minutes.
The results of the pilot show that the participants of TOU tariff saved 30 percent of their average bill, while participants of the real time pricing group saved 27 percent, compared to the control group. The difference in the average energy consumption between the groups was small, but statistically significant. The participants of the TOU group consumed 21 percent less electricity and achieved conservation benefits. The real time group consumed the same amount as the control group. The result of the experiment shows, that a communication system has a positive impact on the reduction of peak consumption, and therefore reduces the danger of blackouts.
The results of experiments from this group show, that RTP is an effective tool for peak load reduction. The average peak load reduction under RTP tariff is 10%. In all experiments from this group consumers achieved bill savings (Faruqui & Sergici, 2008).
The majority of those 17 experiments showed that customers respond to a high price in peak periods. Consumers diminished their consumption in high-price times, or shifted their consumption to a cheaper period of time. Across the range of experiments, the average data shows that the TOU tariff has the lowest impact on peak load reduction (3-6%). Under RTP the average peak load reduction amounted 10%. CPP tariff has the highest impact on peak load reduction. Under CPP the average peak consumption was reduced by 13-20%.The availability

of necessary technologies significantly increases residential demand response (Faruqui & Sergici, 2009).

Figure 8: Summary of the demand impact



Source: Faruqui & Sergici, 2009, p. 41

Under dynamic tariffs consumers have risks of significant price volatility. Benefits, which participants could get from dynamic tariffs, are likely, but not certainly should occur. In case of ineffective consumption, costs for the necessary equipment can overweight the benefits from dynamic pricing (Allcott, 2009). Therefore, it is logical to expect that dynamic tariffs could significantly hurt low-income customers. A recent group of field experiments were done to analyze the responsiveness of low-income customers to different dynamic tariffs, and to estimate their impact on low-income consumers.

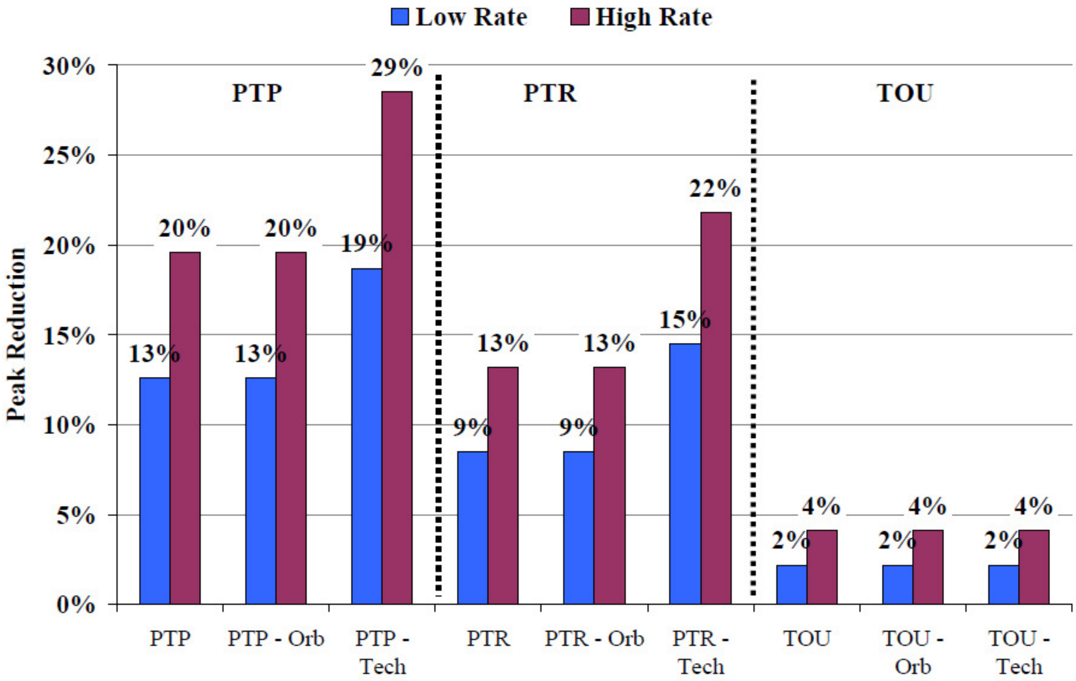
The California Statewide Pricing Pilot (July 2003-December 2004) was designed to measure how electricity consumers of different income levels respond to dynamic pricing. The experiment was based on two dynamic tariffs: Time-of-Use (TOU) rate, in which relation of the peak to off-peak price was roughly 2:1; Critical Peak Pricing (CPP) tariff, in which the relation of the critical peak to off-peak price was 6:1. The participants were divided into two income groups. The experiment consisted of three tracks: Track A- participants represented California's population; Track B- participants, represented electricity consumers of a low-income community; Track C- participants represented consumers of San Diego that had volunteered for a prior smart thermostat program. The results of the experiment have showed that high income consumers were more price-responsive than low income. However, the difference was not large, and low income customers also exhibited demand response. Participants with a high income have reduced their consumption by 16%, while low income customers achieved an average peak load reduction of 11% (Faruqui & Sergici, 2010).

The BGE Smart Energy Pricing (SEP) Pilot tested the impact of income level on the example of three pricing policies: a dynamic peak pricing (DPP) tariff; a "low" peak time rebate (PTRL), and a "high" peak time rebate (PTRH). The participants of the experiment were divided into two income groups and were equipped with two different technologies: the Energy Orb and a switch for cycling air conditioners. The results indicated that participants' income level did not have a significant effect on their electricity demand response. However, enabling technologies increased the price response significantly. In the absence of technologies the average peak load reduction, among both groups was in a range from 18 to 21 percent. With the presence of both technologies, the impacts ranged from 28 to 33 percent.

The PEPCO PowerCentsDC program took place in Columbia in 2008-2009. Three different price structures were proposed for the participants: Critical Peak Pricing (CPP); Critical Peak Rebate (CPR); Hourly Pricing (HP). The participants of the program were electricity consumers with a low- and high-income level. The program design specified that low income participants could only be placed on the CPR rate. The result showed that low-income customers on the CPR (the only rate that was offered to the low income customers) exhibited on average bigger peak reductions than the high-income customers.

Another experiment from Faruqui & Sergici (2010) is the CL& P Plan/it Wise Energy Program-Connecticut. On that experiment residential customers were divided for those who received a dynamic rate and those who stayed on their current rate. In the experiment three dynamic tariffs were tested: Time-of-Use (TOU), Peak Time Pricing (PTP), and Peak Time Rebate (PTR) for two income groups (low and high). As in the New Jersey (GPU) pilot, in the current experiment high and low tariff rates were tested. The results of the experiment show that a PTP tariff has the greatest impact on customers, while a TOU tariff has the lowest impact. Consumers on the PTP rate reduced their consumption during peak periods up to 29%, while customers of the TOU tariff reduced their peak-consumption only up to 4 %. The results have also confirmed the expectation that higher tariffs lead to higher peak load reduction rates.

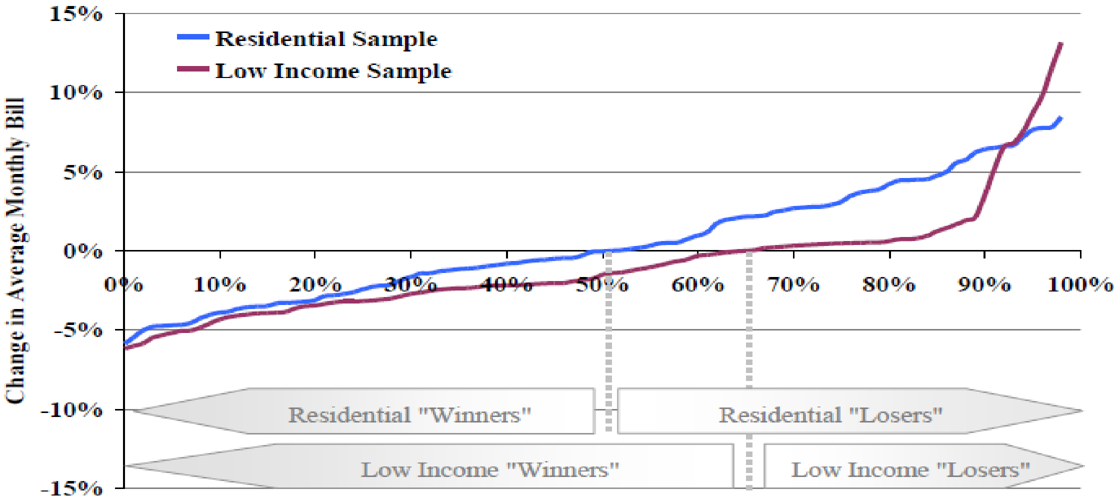
Figure 9: Percent of peak load reduction based on Plan-it Wise pilot, 2009



Source: Faruqui & Sergici, 2010, p.18

The results of the experiment also support the idea of income level insignificancy. "Results indicated that hardship customers responded slightly less than the average treatment customers" (Faruqui & Sergici, 2010 p.18). The experiment shows that dynamic tariffs have a positive effect on low income consumers. Consumers with a low income level respond to dynamic pricing on the same way, as consumers with a high income level. Moreover, many low income consumers may benefit even without shifting their load. The reason for this is, that a high percentage of consumers with a low income level, have flatter load shapes than the average (Faruqui & Sergici, 2010).

Figure 10: Distribution of dynamic pricing, bill impacts



Source: Faruqui & Sergici, 2010, p.27

The percentage of low income consumers, who get a benefit from dynamic tariffs, depends on the rate design itself. Compared to the TOU tariff and RTP, low income consumers get the highest benefit under CPP tariff (Faruqui & Sergici, 2010).

Concerning the laboratory experiments, there are two types of experiments: single-side experiments and two-side experiments. The experimental paper from Rassenti, Smith and Wilson (2002) is a good example for supply-side as well as both-side laboratory experiments. In the experiment from Rassenti et al. (2002) an electricity market was constructed without a demand side. Therefore, consumers, who represented the demand side, were replaced by computers. In the next treatment computers were replaced by profit motivated human subjects. In the second treatment participants were informed about costs for electricity generation. The number of electricity-units, which consumers could purchase, varied during the day. The results of the experiment show that the introduction of a demand-side diminishes the wholesale market price significantly. It also eliminates price spikes. The result shows that prices for electricity varied more under demand-side bidding and the price level was lower, compared to the first treatment. Without demand side bidding, sellers pushed prices up to capture the surplus between demand and costs for electricity generation. In the second treatment, the sales price was by 12, 5 experimental dollars lower, than in the first treatment. The sales price diminished because buyers refused to purchase electricity at the high price (Rassenti et al. 2002).

Adilov et al. (2004; 2005) reported two additional experiments with one-sided and two-sided electricity markets. The purpose of both papers was to test the efficiency of two forms of the active demand-side participation. The participants of the experiment faced different experimental price regimes: fixed price, where participants needed to pay a fixed tariff for electricity; demand response feature (DRF), where participants needed to pay a fixed tariff, but they received a credit for reduced consumption; a real time pricing system (RTP), where prices were forecasted for the upcoming day-night. The main conclusion of both papers is that, residential demand is elastic and the real time program (RTP) results in the greatest demand reduction. Both DRF and RTP reduced price spikes (Adilov et al. 2004; 2005).

One of the recent laboratory experiments is presented by Barreda-Tarrazona et al. (2012). In the experiment three price regimes were compared: fixed price (FP); critical peak pricing (CPP); critical peak rebate (CPR). In the experiment, consumers who differ in their willingness to pay for electricity needed to decide how much of transferable and non-transferable energy to buy during peak and valley periods. The experiment showed that dynamic pricing regimes reduce the consumption in the peak period and slightly increase it in the valley period. It leads to an overall reduction of the energy consumption (Barreda-Tarrazona, 2012).

In the laboratory experiment from Wolak (2010) was estimated whether a demand response to dynamic pricing depends on income level. Two groups of participants were subject to two tariffs: a pure CPP tariff versus a CPP with rebate (CPR). The results of the experiment showed that there was a demand reduction in response to high hourly prices in CPP periods across all type of consumers. The reduction rates of the low income customers were insignificantly higher, compared to the reduction rate of the high income customers (Wolak, 2010).

The existing literature suggests that residential consumers respond to dynamic tariffs regardless of their income level. However, the elasticity of demand highly depends on the price structure. In contrast to the predictions of the standard economic theory, price structures do matter for the consumer's decision making and welfare. OFT (Office of Fair Trading) from London estimated how different price structures influence consumer's behaviour. The result of the experiment suggests that consumers make more mistakes and achieve lower welfare under price frames (OFT, 2010).

Ascaraza et al. (2012) analysed how different tariff structures affect consumer's behaviour in a telecommunication service. In the experiment subjects needed to consume units (minutes) of a telecommunication service under two different tariffs: two-part and three part tariffs. A two-part tariff is a price system, where consumers need to pay a fixed price per unit of consumption and a fee for the access to the telecommunication service. A three-part tariff is a tariff, where consumers need to pay a usage price, only in case of exceeding the usage allowance. Within the allowance, usage is "free". The experiment showed, that consumers under the three-part tariff significantly “overuse” their allowance, compared to their consumption under the two- part tariff. “83.9% of three-part tariff users value minutes on a three-part tariff more than they would on a two-part tariff” (Ascaraza et al. 2012 p.1).This finding suggests, that under different price structures consumers do not always make a choice, which leads to a bill saving.

4. The possibility of implementing dynamic pricing in the Ukrainian electricity market

4.1. *Relevance of demand response programs to the Ukrainian electricity market*

Ukraine's energy sector faces great problems, because of dependence on expensive fossil-fuel imports and inefficient energy consumption (IEA, 2012; Dodonov et al. 2001). The main reason of the inefficient energy consumption in Ukraine is the low residential tariff for electricity. The residential electricity tariff is much lower than costs for its production. This situation leads to an additional outlay of budgetary funds for subsidizing the energy sector (Tsarenko 2007, 2008). The logical solution for the Ukrainian electricity market would be to increase the residential tariffs. However, taking into consideration the Ukrainian "non-payment" problem, and the relatively low population's income level, this action only would lead for further debt accumulation (Horn, 1998). Due to low electricity tariffs, the demand for electricity continuously raises (Raptsun, 1999). The Ukraine's electricity sector is ageing and deteriorated. Therefore, the Ukrainian power sector will soon face a difficulty to satisfy the continuously growing demand. Bad technical conditions of the electricity sector influence also the environmental situation in the country. Due to bad technical conditions, emissions to the atmosphere have increased. Upgrading of power plants to limit the quantity of emissions would require investments of 10 billion US $ to 12 billion US $ (IEA, 2012).

The advantage of demand response programs for the Ukrainian electricity market is in the ability to optimize the electricity consumption without significant increases of electricity tariffs. Implementing DR programs into the Ukrainian electricity market would solve the problem of inefficient electricity consumption and would attract investments, due to the increased system reliability. It also would diminish emissions, due to the lowered need for electricity generation (IEA DRR, 2006).

Public utilities in Ukraine are not profitable. A movement to a market-based price for electricity would ensure that the energy companies would become economically viable (Chen Lin, 2005). Implementing DR programs into the Ukraine's electricity market will boost economic growth and improve energy supply security. At the moment, the reformation of the Ukraine's electricity-supply sector is on the initial stage and will require a great scale of investments, complemented by a substantial reform of the business environment (IEA, 2012).

4.2. *Overview of the Ukrainian electricity market*

Ukraine is one of the first countries of the former Soviet Union, which orientated its electricity policy to the liberalization of the electricity market.

In order to improve the competitive ability of the electricity sector, Ukraine established the Wholesale Electricity Market (WEM) in 1996 (Tsarenko, 2008).

As of today, following participants carry out activities in the Ukrainian electricity market: 93 generators; one wholesale electric power supplier (Energorynok); the state-owned national grid company (Ukrenergo); the distribution companies (Oblenergos).

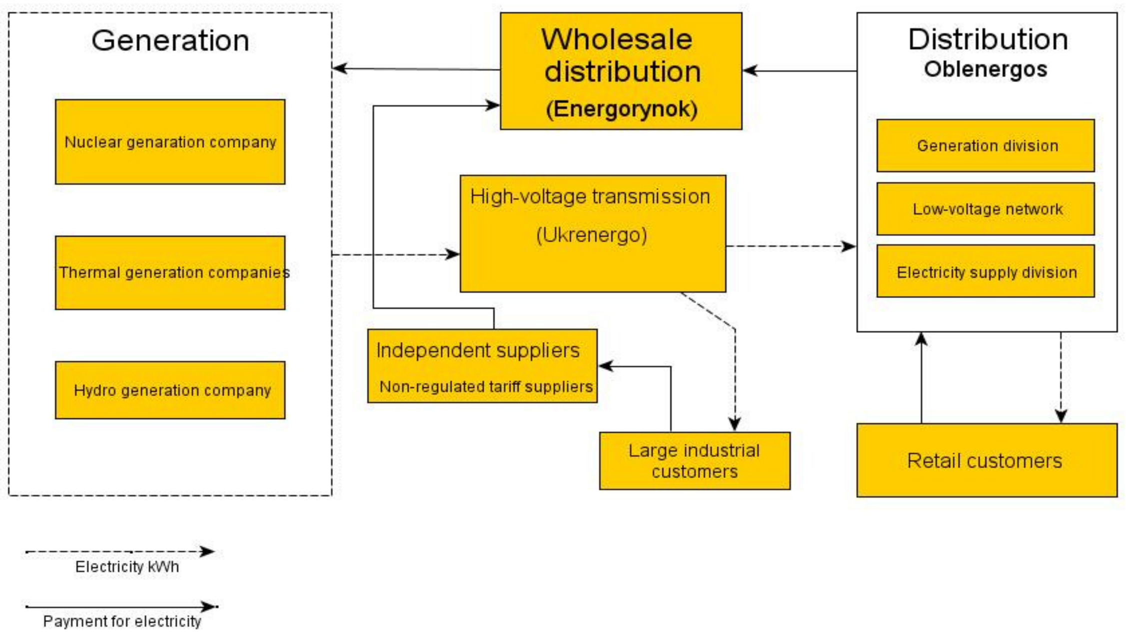
Energorynok is a state-owned company that buys electricity on the wholesale market and sells it to the distribution companies (Oblenergos) and to the independent suppliers.

Oblenergos are regional distribution companies that operate the low voltage network. The state is the main shareholder in the majority of distribution companies.

Ukrenergo is a state-owned company that provides energy through the transmission lines to the distribution companies. The company operates the high voltage network.

Independent suppliers also purchase electricity on the wholesale market and resell it on unregulated tariffs. Their market share does not exceed 15 % (Tsarenko, 2007; 2008).

Figure 11: Participants of the Ukrainian electricity sector



Source: own illustration on basis of Tsarenko (Tsarenko, 2007, p.8)

There are three types of generation in Ukraine: thermal power plants; hydroelectric plants; nuclear power plants. The percentage of alternative energy generators, like wind and helium power plants, is insignificant but progressively increases (Tsarenko, 2007).

The Ukrainian electricity sector is Europe's sixth largest after Germany, France, Italy, Spain and Great Britain. The total capacity of all electricity generators was 52, 08 GW in 2010. The highest installed capacity is represented by thermal (64, 3 %) and nuclear power plants (26, 5 %) (DTEK, 2011). However, the quantity of generated electricity over the years differs from the installed capacity.

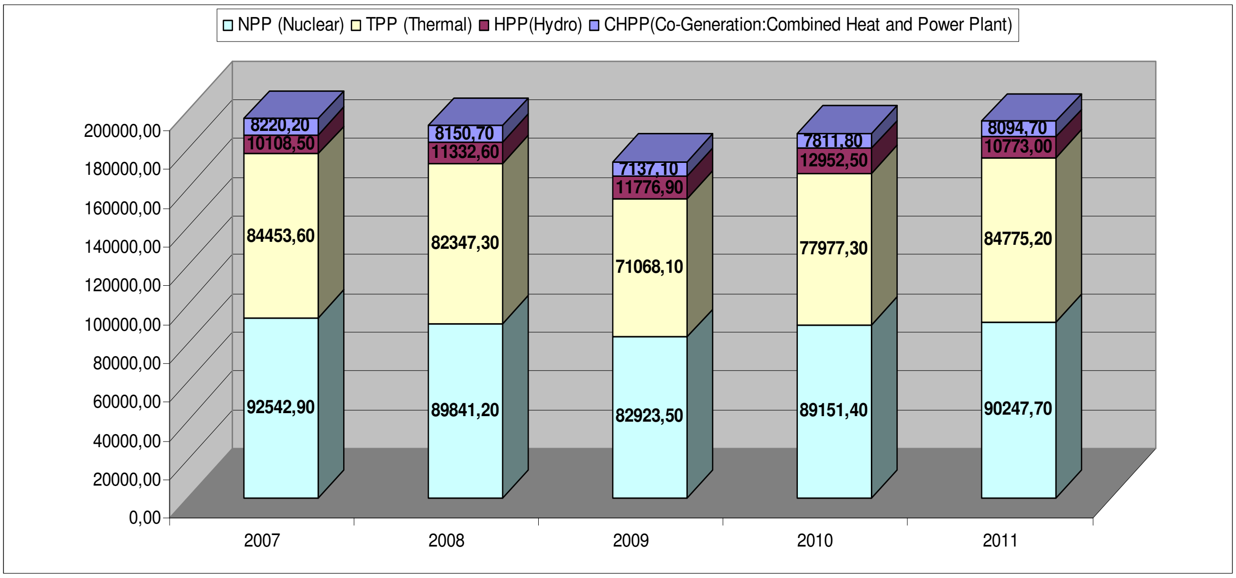
Table 5: Low capacity factor

	Installed capacity		**Generation**		**Capacity factor**	**World average**
	GW	*Share*	*TWh*	*Share*	*%*	*%*
Thermal	33,5	64,30%	78	45,20%	27%	60-70%
Nuclear	13,8	26,50%	83	47,90%	69%	91%
Hydro	4,70	9,00%	12,00	6,90%	29%	44%
Wind	0,08	0,20%	0,05	0,00%	7%	20-40%
Total	**52,08**	**100,00%**	**173,05**	**100,00%**	**38%**	

Source: DIFFER, 2012, p.2

Thermal power plants have a significant overcapacity compared to the existing demand. Due to the inefficient generation, thermal power plants have high production costs. Since thermal power plants depend on margin, this results in a high competition between power plants. In 2010 the average capacity factor for thermal power plants was only 27 %. The average capacity factor shows the quantity of the installed capacity, which was in operation over the year. Inefficient use of the installed capacity occurs due to the unpredictable demand (DIFFER 2012).

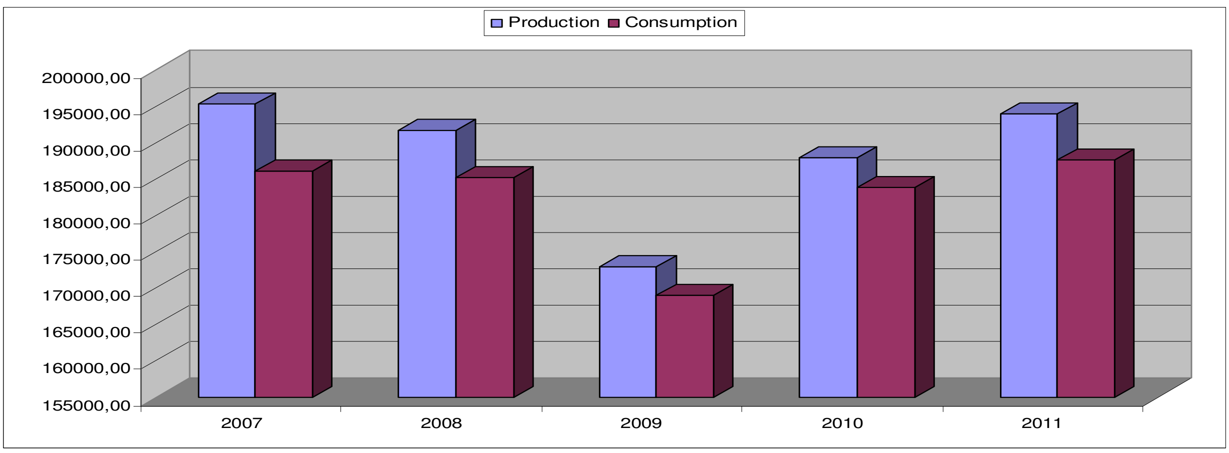
Figure 12: Ukrainian energy production (billion kWh)



Source: own illustration based on data from ministry of fuel and energy of Ukraine

The majority of electricity in Ukraine is generated by thermal and nuclear power plants (Tsarenko, 2008). Ukraine increased its electricity generation in 2011 by 3, 2 % up to 193, 9 billion kWh. NPPs increased the production by 1, 2 % up to 90, 2 billion kWh. TPPs and CHPPs increased by 8, 7 % up to 84, 8 billion kWh, while HPPs decreased production by 16, 8 % down to 10, 78 billion kWh due to low water inflow (DTEK, 2011).
The main consumers of electricity in Ukraine are households and domestic industries. From 2010 the average level of consumption increased by 2.0 % and reached a 188 billion kWh in 2011 (Ministry of Fuel and Energy of Ukraine).

Figure 13: Energy balance in Ukraine (million kWh)



Source: own illustration based on data from ministry of fuel and energy of Ukraine

Approximately 4 % of the produced electricity is exported to the neighbour countries (DIFFER, 2012).

4.3. *Energy price*

4.3.1. Wholesale pricing

The wholesale electricity market in Ukraine was established in 1996. It is a “single buyer” model, where Energorynok buys all electricity from the generators and resells it to distribution companies and independent suppliers. According to the price setting, the wholesale electricity market in Ukraine is divided into two submarkets: generators’ market and suppliers’ market (Tsarenko, 2008; DTEK, 2011; DIFFER, 2012).

Generators’ market

The generators’ market is divided into two types: regulated and competitive markets. The regulated generators’ market is a market where the wholesale price for generators is defined. To the regulated generators’ market belongs all electricity produced by all Ukrainian generators, except the electricity generated by thermal power plants. All those generators generate electricity under regulated costs, which are approved by NERC (National Electricity Regulation Commission of Ukraine). 68 % of the generators’ market tariffs are regulated. The remaining 32% belong to a competitive wholesale market, which is represented by the thermal generation segment. The wholesale price on the competitive generator market is determined under a day-ahead bidding principle (Tsarenko, 2008). Thermal power plants bid for which price they are able to produce the necessary (forecasted) quantity of electricity. Energorynok draws up a system to load the power units from the less costly to the highest. At the end, the first power units to be loaded are those that submit the lowest bids. “The last satisfied bid determines the base price for electricity at all loaded TPP power units. So generation companies with the lowest production cost get the highest load and margin” (DTEK, 2011 p.38).

The average wholesale price from generators is defined by the intersection of the competitive and the regulated wholesale market price (Tsarenko, 2008).

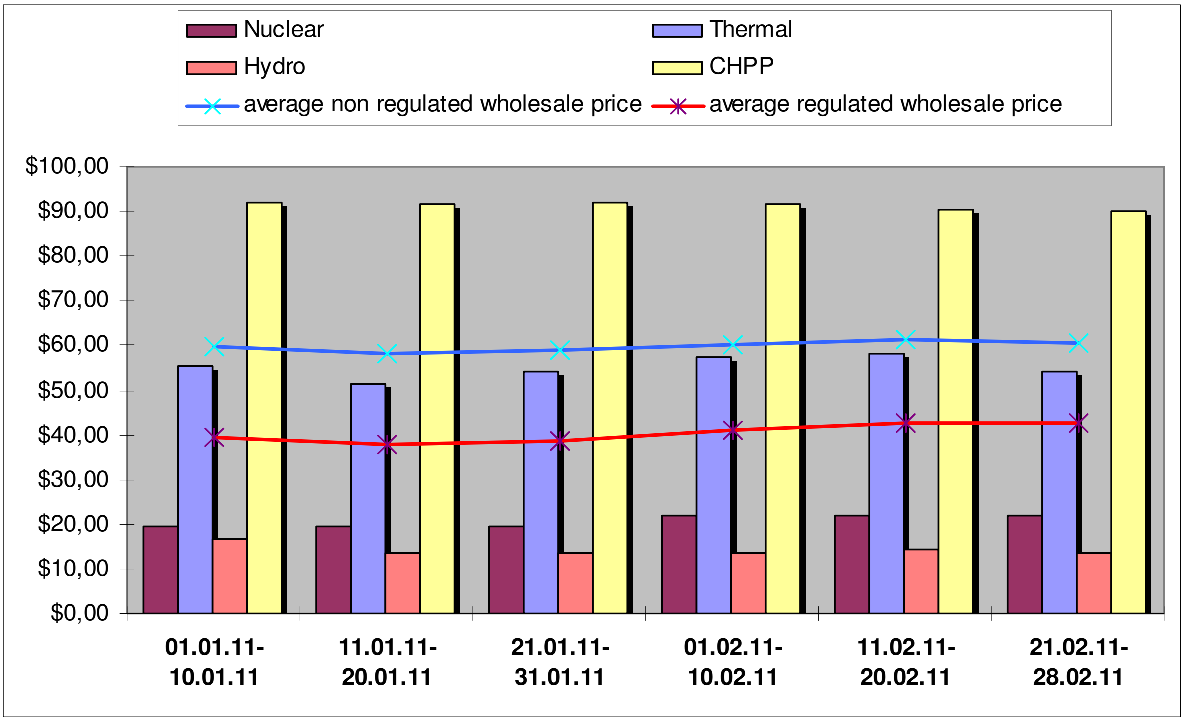
Suppliers' market

The suppliers' market is a market where the price for suppliers is defined. The average price for suppliers is calculated on the base of the average wholesale price from producers. It also includes additional payments and compensation certificates. Additional payments mean the cost for administrative functions of Energorynok, as well as payments to Ukrenergo for high-voltage transmission. Compensation certificates are a kind of compensation fees paid to the suppliers of electricity to compensate the loss from electricity supply to the preferential types of customers. The preferential types of customers are: households, agriculture sector, coal producing companies etc (Tsarenko, 2008). In 2011, UAH 28 billion (USD 3, 5 billion) were subsided, to cover financial losses due to energy supply to those type of consumers. Preferential type of consumers pays a corresponding fixed price for electricity, which is proved by NERC, for each type of customers. Households belong to the preferential type of customers, because their utility bills exceed 20 percent of their income (Mitra & Atoyan, 2012). Households' tariffs are lower, than the price which a supplier, who works on a regulated tariff, should pay for the electricity purchase. This difference is compensated from government funds. Those subsidies consisted 30 % of the wholesale electricity price in 2011.

A supplier which works under the regulated tariff should pay a final price for the purchased electricity, excluding the amount covered by compensation certificates. Therefore, the average wholesale price for the regulated tariff suppliers is lower than the average wholesale price for the non-regulated tariff suppliers. Non- regulated tariff suppliers achieve their profit by setting high consumer tariffs. The customers of non-regulated suppliers are large industrial customers, or intermediate companies, which supply electricity to large customers (Tsarenko, 2008).

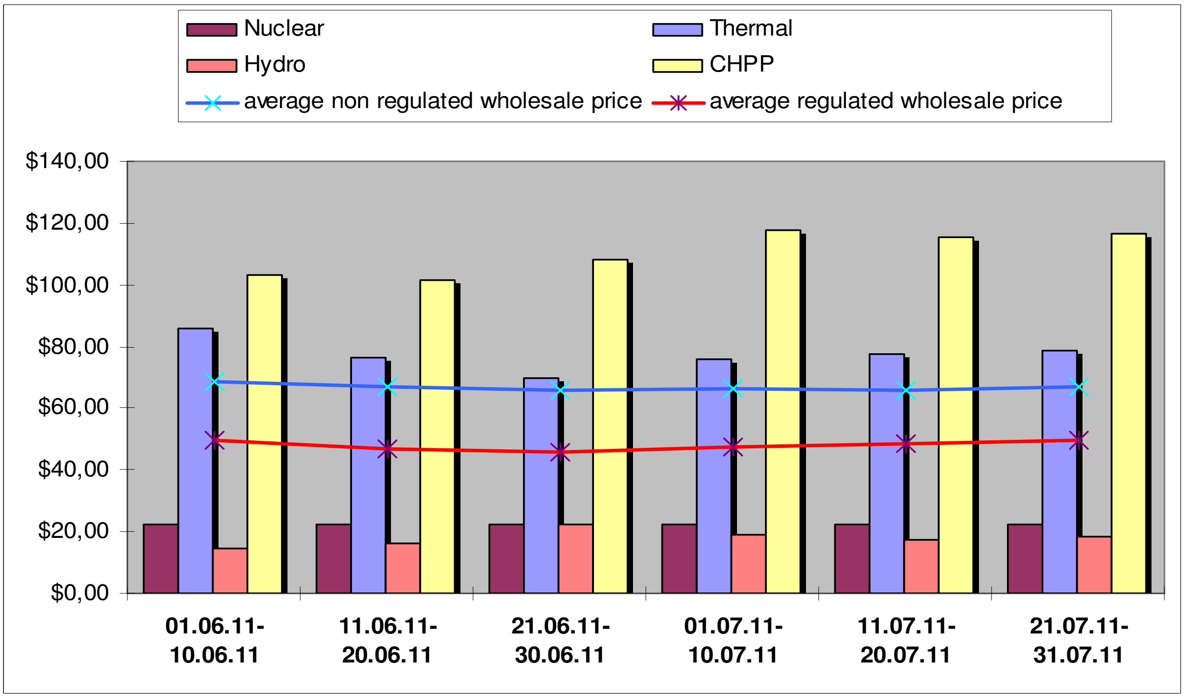
Due to the government intervention in the price formation, there is no significant price volatility on the wholesale market. However, the regulated price is significantly lower than the non-regulated. The regulated tariff rate is higher at summer time, than at winter time.

Figure 14: The wholesale electricity price variation in period 01.01.2011-28.02.2011



Source: own illustration based on data from ministry of fuel and energy of Ukraine

Figure 15: The wholesale electricity price in period 01.06.2011-30.06.2011



Source: own illustration based on data from ministry of fuel and energy of Ukraine

4.3.2. Retail pricing

All electricity consumers in Ukraine are divided into two groups: consumers with regulated tariffs and consumers with non-regulated tariffs. Non-regulated tariffs are applicable for large customers, while regulated tariffs are for small industrial customers and households. Those consumers who pay regulated tariffs are divided into two classes: consumers connected to the high-voltage grid (first class); customers that are connected to the low-voltage grid (second class).

The high-voltage grid is more than 27, 5 kV, while the low-voltage grid is up to 27, 5 kV.

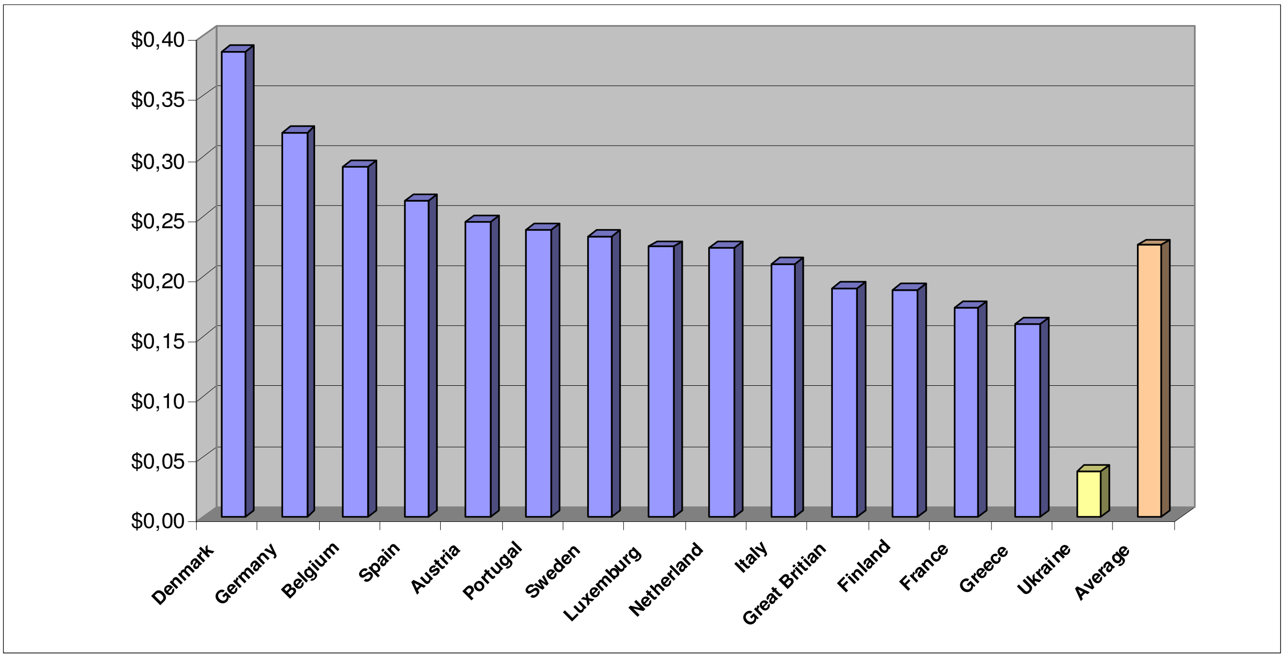
The regulated tariffs are set by supply companies and regulated by the National Electricity Regulation Commission of Ukraine (NERC). NERC was established in 1995 and its responsibilities are: implementation of pricing and tariff policy; protection of electricity consumers' rights; regulation of natural monopolies in the electricity sector (Tsarenko, 2008). Bases for setting a regulated tariff for the end-customers are the average wholesale price and the cost for transmission (DTEK, 2011).

Non-regulated tariffs are set by independent suppliers and depend on the wholesale average price (Tsarenko, 2008).

The electricity tariffs in Ukraine consist of: costs for the generation, transmission, distribution and supply. The costs for generation depend on the time of the electricity load. Costs for transmission depend on the load, and therefore it differs for different groups of consumers. The distribution price varies between different voltage levels. Therefore, electricity tariffs in Ukraine vary between different customer groups (Dodonov et al. 2001).

Energy prices, for residential households are significantly lower in Ukraine than the prices in the rest of Europe. Most energy prices cover only the operating costs and do not include long-term costs of the energy supply. The end customer tariff covers only 60 % of the production cost (Tsarenko, 2008).

Figure 16: Electricity tariffs for population in Europe (US$/kWh)



Source: own illustration on basis of DTEK (DTEK, 2011, p.40)

In Ukraine, a consumer, who consumes less than 150 kWh per month, pays 23, 35 kopecks (2, 9 US cents) per kWh net of VAT. Every kWh of electricity that exceeds this point costs 30, 40 kopecks (3, 8 US cents) (DTEK, 2011).

Electricity tariffs for households are subsidized, because of the strong conviction that low-income households will not be able to pay tariffs, which would cover long-run marginal costs. Therefore, NERC sets a fixed tariff, which is supposed to be low enough to allow customers to pay their bills (Dodonov et al. 2001).

The inefficient energy price structure is the cause of the main technical and financial problems that faces the Ukrainian electricity market.

4.4. *Key problems of the Ukrainian electricity market*

Due to very low tariffs, consumers do not have incentives to consume electricity in an efficient way (Tsarenko, 2008; DTEK, 2011).

Inefficient consumption led to technical problems. The growing demand for electricity cannot be satisfied by using the old transmission and distribution system. Therefore, temporal electricity blackouts occur through the country (DTEK, 2011).

The Ukrainian electricity system is deteriorate and requires upgrades. The level of technological losses came up to 11, 9 % of the total electricity produced, or to 21, 1 billion kWh. It is 2 to 2, 5 times higher than on developed countries. Ukraine has a significant generating capacity, but nearly 12 % of the generated electricity is lost (Tsarenko, 2008). Transmission losses are caused by the insufficient condition of the transmission grid (Chen Lin, 2005). Therefore, the quantity of generated electricity should be significantly higher than the demand for electricity. The problem of losses can be solved by investments on the distribution and transmission network (Tsarenko, 2008). However, subsidizing of electricity tariffs withdraws government funds which could be spent for the modernization of the energy sector. The Ukraine's electricity sector also suffers from the significant amount of non-technical losses, i.e. fraud. Many consumers inherit from the Soviet Union time to manipulate electricity counters and to consider electricity, as a public good, which they should receive for free (Dodonov, 2001). Non-technical losses represent a sizable amount of the utilities' financial losses. The classical case of fraud in Ukraine is the unauthorized connection to the grid or tampering of the electricity meters. As a result, consumers are able to consume electricity for which they do not pay. Therefore, the commercial performance of the distribution companies is quite poor (Antmann, 2009).

Under fixed tariff, the demand for electricity is unpredictable. Unpredictable demand leads to inefficient energy production. Therefore, a large amount of the Ukrainian power plants generate electricity below the installed capacity level.

Introducing DR programs into the Ukrainian electricity market is the solution which would diminish the level of the expensive peak-time consumption and would not adversely affect the living conditions of low-income customers (Park, 2011). DR programs would improve the commercial performance of the distribution companies, by diminishing non-technical losses. However, before to introduce dynamic tariffs, it is important to estimate the country's potential for demand response.

4.5. *Demand response potential in Ukraine*

The potential for implementing DR programs into the electricity market is studied through estimation of the market, economic and technical potential (Goldman et al. 2007).

4.5.1. Market potential

The main consumers of electricity in Ukraine are domestic industries and households.

Table 6: Electricity consumption in Ukraine, by sources

Consumption category	2010	2011	Change	Change	2010	2011
				%	share %	share %
Consumption (gross)	183908,5	187647	3738,5	2		
Consumption (net)	147483,4	150967	3483,6	2,4	100	100
1. Industry, including:	71517,3	73037,9	1520,6	2,1	48,5	48,4
metallurgy	38438,1	37674,8	-763,3	-2	26,1	25
fuel	9397,3	9532,4	135,1	1,4	6,4	6,3
engineering	5961,8	6446	484,2	8,1	4	4,3
chemical and petrochemical	5328,2	6267,5	939,3	17,6	3,6	4,2
food and processing	4623,2	4664,1	40,9	0,9	3,1	3,1
construction materials	2425,8	2696,7	270,9	11,2	1,6	1,8
other industry	5342,9	5756,3	413,4	7,7	3,6	3,8
2. Agriculture	3394,4	3526,9	132,5	3,9	2,3	2,3
3. Transport	9451,1	9916,4	465,3	4,9	6,4	6,6
4. Construction	951,4	952,6	1,2	0,1	0,6	0,6
5. Communal-household consumption	18282	18369,3	87,3	0,5	12,4	12,2
6. Other non-commercial consumption	6213,3	6554,7	341,4	5,5	4,2	4,3
7. Households	37673,9	38609,1	935,2	2,5	25,5	25,6

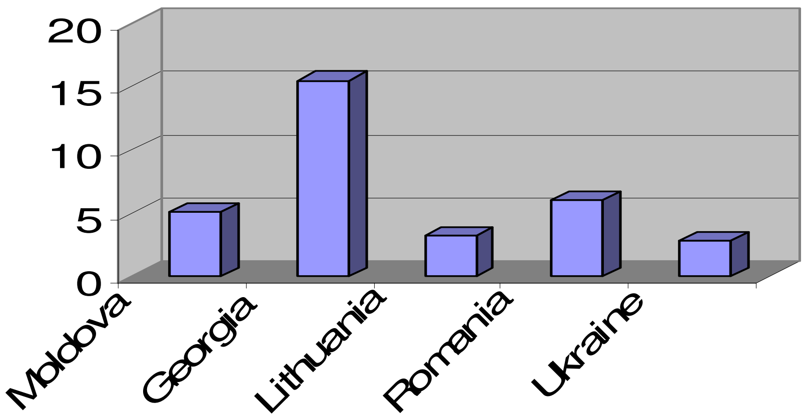
Source: DTEK, 2011, p.38

Due to the low electricity tariffs, the population does not have incentives to consume in a more effective way. Increasing the tariff levels for electricity would support the economy of Ukraine, as well as increase the penetration of DR programs. However, the increase of tariffs could create a negative effect (Fankhauser & Tepic, 2005). According to a Gorshenin Institute research, the increase of electricity tariffs to the cost-coverage level will result in that 73, 3 % of Ukrainian population will diminish their electricity consumption and the rest of people will not pay for electricity at all. In developed countries this type of “non-payment” phenomenon does not exist. Therefore, the definition “electricity demand” in developed economies reflects the quantity of electricity which customers are willing and able to pay. By contrast, in Ukraine, the “electricity demand” equals to the supplied quantity of electricity, which may or may not be paid for (Horn, 1998). However, the “non-payment” problem can be viewed from different ways. On one side, in Ukraine there is a significant amount of households, who leave below poverty level, and not able to pay their bills. On the other side, Ukraine’s law does not provide any punishment for non-payers, such as disconnection from the energy supply, or sequestration of debt (Dodonov et al. 2001). Therefore, it should be a distinction between the ability to pay and the willingness to pay.

Fankhauser and Tepic (2005) evaluated the average share of Ukraine's household's monthly income that is spent for electricity. According to their evaluation, this amount does not exceed 2, 1 percent. To assume that utility services are not affordable for consumers it is important to determine the acceptable level of utility service expenditures. This level varies between countries. For the Ukrainian households the utility services are considered to be not affordable if the expenditures for it exceed 20 % of the household's monthly income. Expenditures for electricity should not exceed 10% of the household's monthly income.

The research from Fankhauser and Tepic (2005) shows, that affordability of electricity is not an issue for the majority of transition countries. Moreover, Ukrainian households spend a significantly lower amount of their income for electricity bills compared to the other transition countries.

Figure 17: Level of electricity affordability

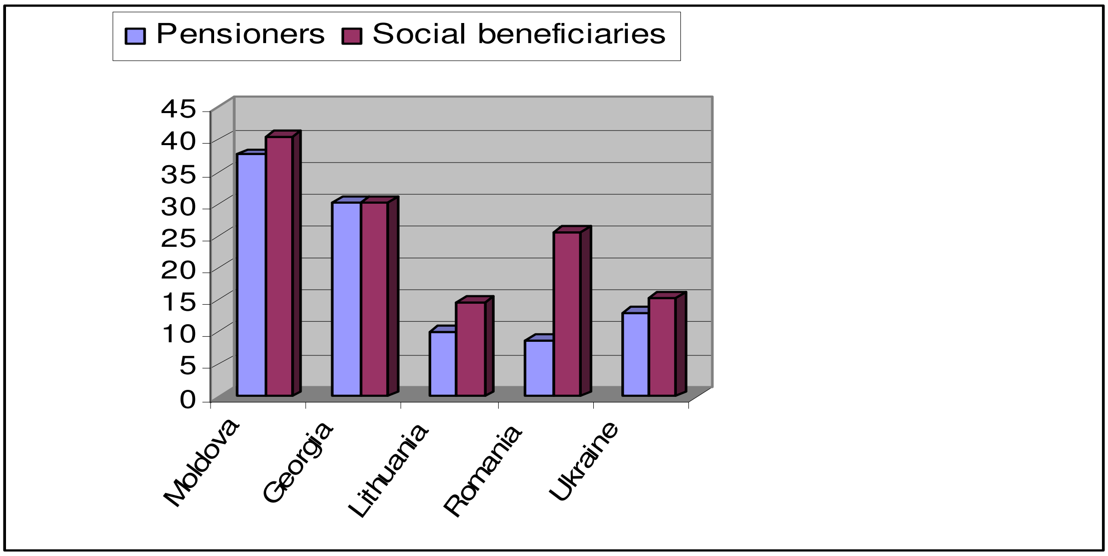


Source: own illustration on basis of Fankhauser & Tepic (Fankhauser & Tepic, 2005, p.8)

However, this estimation is based on the observation of the average household.

More precise data regarding the affordability of electricity tariffs gives the affordability rate for low-income customers. The "non-payment" problem also has to be included to this estimation. Therefore, Fankhauser and Tepic (2005) estimated the level of electricity tariffs affordability for the social vulnerable customer segment in case of full payment.

Figure 18: Level of electricity affordability in case of full payment



Source: **own illustration on basis of Fankhauser &Tepic (Fankhauser & Tepic, 2005, p.24)**

Observed results suggest, that even at the current low tariff levels, but with the assumption of full-payment, paying of electricity bills is problematic for many vulnerable Ukrainian customers (Fankhauser & Tepic, 2005)**.**

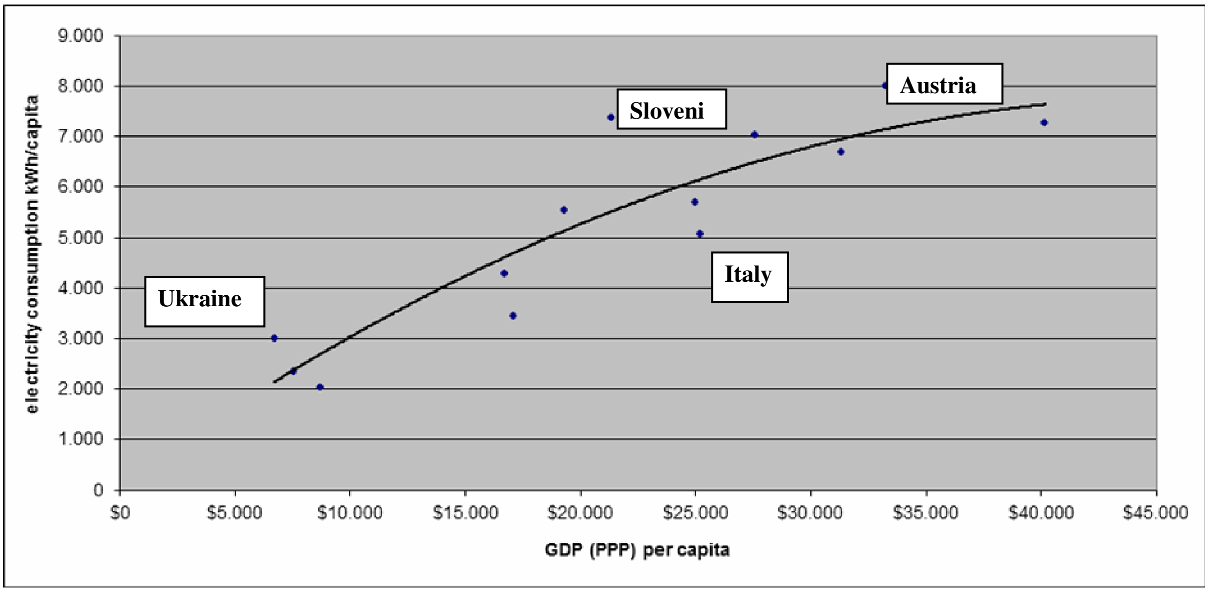
Due to the non-payment problem, electricity tariffs are subsidized even more than for the value equal to the difference between the existing electricity tariff and costs for generation (Dodonov et al. 2001).

Ukraine has a sufficient market potential for DR programs. The increase of the electricity tariffs is not an option for the Ukrainian electricity market. The development of appropriate dynamic tariffs would solve the "non-payment" problem and would not harm the socially vulnerable population. By shifting electricity consumptions from more expensive periods to cheaper periods of time, consumers could "adjust" their electricity bills to a level, which is appropriate for them. On the other side, the "non- payment problem" is also one of the barriers for implementing DR programs. By accumulating the debt for utility services, residential consumers take government's funds out of turnover. In case of full payments this funds could be spent for the development of DR programs.

4.5.2. Economic potential

The level of economic development in the country has a relation to the demand response potential. Economic growth influences the electricity demand. There is a positive correlation between the growth of the GDP level and the level of electricity consumption. GDP growth represents an increased economic activity, and available income. This both factors are positively correlated with the energy consumption (CASES, 2007).

Figure 19: Development of the GDP level and electricity consumption



Source: own illustration on basis of data from Eurostat

The comparison of the ratio of electricity consumption and GDP of the European countries indicates that the Ukrainian electricity consumption is relatively high compared to its GDP per capita. This ratio is much higher than in Western Europe and the USA. The negative factor is that the trend towards growing electricity consumption per unit of GDP has also increased (Raptsun, 1999).

The energy price is one of the important drivers for more effective electricity usage. Energy use depends on the economic and environmental circumstances, and the energy efficiency measures how effective energy is used under these circumstances (Cornillie & Fankhauser, 2004). On the example of Ukraine's economy we can see, that underpricing of household electricity led to inefficient energy consumption. Underpricing of electricity is used due to the inability of low-income customers to pay their electricity bills (Fankhauser & Tepic, 2005).

According to the Ministry of Labor the average annual households' income amounted to $ 4450, 00 per person in 2011. However, approximately half a million of Ukraine's population receive salaries lower than the government proved living wages, and have a difficulty to pay utility services (Ministry of Labor of Ukraine).

Table 7: Official living wages in Ukraine

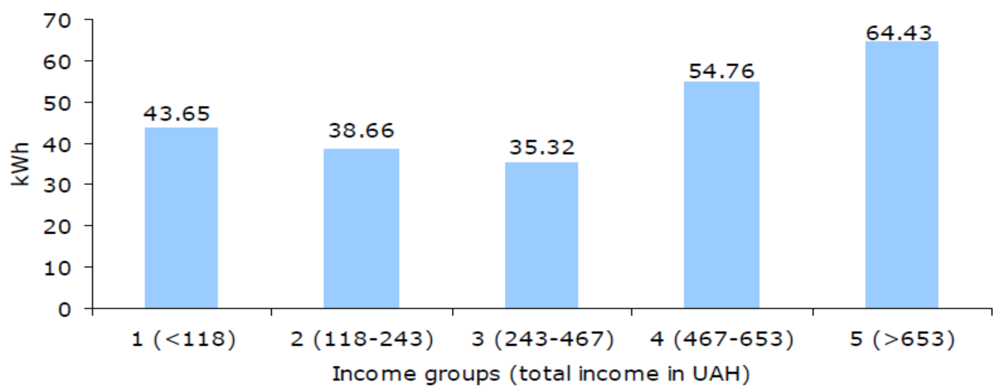
Social and demographical groups of people	Living wages			
	01.01.2011 – 31.03.2011	01.04.2011 – 30.09.2011	01.10.2011 – 30.11.2011	01.12.2011 – 31.12.2011
People which are able to work	\$114,00	\$116,00	\$119,00	\$122,30
Disabled people	\$91,00	\$93,00	\$95,50	\$97,40

Source: data from the ministry **of Labor of Ukraine**

However, underpricing of electricity tariffs is a bad instrument to achieve distributional or welfare objectives. While low electricity tariffs support consumers with a low income, they also favor wealth situated households (Mirta & Atoyan. 2012).

Dodonov (2001) analyzed the current situation on the Ukrainian market and investigated how much the increase of electricity tariffs will hurt the poor population. The results of the experiment are based on the observation of 126 Ukrainian households, which were divided into 5 income groups. Due to different income levels the participants had a different number of electric appliances. The result shows, that under the current tariffs, the variation in the electricity consumption per capita is relatively small among all groups.

Figure 20: Electricity consumption in different income groups



Source: Dodonov et al. 2001, p.11

It means that there is not so much correlation between the consumer's income level and the level of electricity consumption. The interesting fact was, that compared to the second and third income group, the first group, where participants had the lowest income level, had a higher share of households with the highest level of electricity consumption.

Table 8: Share of electricity consumption levels in a different income groups

Level of electricity consumption/ income group	Group1	Group2	Group3	Group4	Group5
high average consumption	36%	23%	18%	56%	71%
medium average consumption	21%	35%	41%	44%	29%
low average consumption	43%	42%	41%	0%	0%
total	100%	100%	100%	100%	100%

Source: Dodonov et al. 2001, p.12

These findings contradict to the assumption of Faruqui & Sergici (2010) that low-income customers consume less energy, than high-income customers do. Therefore, it also contradicts to the assumption that low-income groups will be hurt by dynamic pricing.

However, Dodonov's (2001) research shows that low-income consumers pay a higher fraction of their income compared to high-income consumers. This fact makes it obvious, that the current price policy enriches only households with a high-income level.

However, the increase of electricity tariffs to the cost-coverage level will hurt consumers with a low income (Dodonov et al.2001).

Table 9: Households welfare changes in case of tariffs increase

	Region	Group 1	Group2	Group3	Group4	Group5
Compensating variation (change in electricity expenditures of the equivalent adult in UAH)	Zaporizhya region	1.0	0.9	0.8	1.3	1.5
	Zhytomyr region	3.7	3.2	3.0	4.6	5.4
Compensating variation (change in electricity expenditures of the equivalent adult as a percent of total income)	Zaporizhya region	>0.9%	0.4% - 0.8%	0.2% - 0.3%	0.2% - 0.3%	<0.3%
	Zhytomyr region	>3.1%	1.2% - 2.8%	0.6% - 1.2%	0.5% - 0.6%	<0.8%

Source: Dodonov et al. 2001, p.16

The observed data show that low-income consumers would suffer more from an increase of electricity tariffs (Dodonov et al. 2001).
Taking all mentioned facts into consideration, we can assume that Ukraine does not have a sufficient economic potential for DR programs. The level of the economic growth is significantly smaller compared to the growth of electricity consumption. However, implementing of price-based demand response programs into the Ukrainian electricity market would be a major development compared to the existing price policy. By establishing differentiated tariffs for different periods of the day, a price equal to the cost-coverage level could be reached without an overall tariff level increase.

4.5.3. Technical potential

The sufficient precondition for the implementation of DR programs is a mass roll out of meters, which can store data about the time of electricity consumption. Therefore, a modernisation of the current metering structure is the key to establish dynamic pricing for electricity in the Ukrainian electricity market.
Currently in Ukraine almost all households and middle size consumers are equipped with standard electricity meters, which are read monthly. Distribution network operators are responsible for the installation and maintenance of the electricity meters. The costs for the installation are included in the electricity bills (ERRA, 2008).
Parallel with the existing flat tariff for electricity, Ukraine established time-zoning and multi tariffs coefficients for households in 2012 (NERC Ukraine).

Table 10: Multi-tariffs coefficient valid in Ukraine

	Time period			
	night	**day**	**semi-peak**	**peak**
two-zone tariff				
Tariff coefficient	0,7	1	-	-
Time	from 23:00 till 7:00	from 7:00 till 23:00	-	-
three-zone tariff				
Tariff coefficient	0,4	-	1	1,5
Time	from 23:00 till 7:00	-	from 7:00 till 8:00	from 8:00 till 11:00
			from11:00 till 20:00	from 20:00 till 22:00
			from 22:00 till 23:00	

Source: NERC Ukraine (decree №309 from 10.03. 2012)

The price for electricity is calculated by multiplying the retail tariff by a corresponding dynamic coefficient (NERC Ukraine).

In spite of introducing multi-tariff coefficients, there is no statement from the Ukrainian government that regulates the roll-out of smart meters for households. Furthermore, there is no issue of metering functionalities or technical requirements for the network operators to install smart meters (ERRA, 2008). Therefore, the option of differential tariffs is not widely known and used.

Table 11 presents the costs which bear the Ukrainian households to adopt dynamic tariffs.

Table 11: Cost comparison for the standard and smart meter

Costs	Standard meter	Smart meters	
		two zone meter	**three zone meter**
Average purchase price	$20,70	$185,00	$375,00
Installation price	$10,00-$15,00	$60,00	$60,00
Maintenance cost	-	Not defined	Not defined
Registration on utility companies	$15,00	$20,00	$30,00

Source: data from the electricity provider "Dneproblenergo"

The absence of a cost-benefit analysis for a mass roll-out of smart meters is one of the barriers for the implementation of dynamic price programs in Ukraine. Currently, purchasing and installation costs bear consumers. The cost to purchase smart meters significantly outweighs the purchasing cost of standard meters. Taking into consideration, that the benefits of DR programs are not widely known, households do not have incentives to invest in more expensive equipment.

The market technical potential is often examined in a sense of energy efficiency programs. Energy efficiency is quite similar to demand response. Both affect the consumer's usage of electricity. From the resource outlook, both are demand-side resources (DSM), which may delay the need to construct a new transmission or energy supply infrastructure (Goldman et al. 2007). In 2010, the National Agency of Ukraine for the Effective Use of Energy Resources (NAER) developed a "targeted energy efficiency" program. The target of this program is to improve the energy situation in Ukraine, by investing in technologies supporting alternative sources of electricity generation. The inclusion of demand response programs in the concept of effective electricity use would increase the DR potential in Ukraine.

Based on the mentioned facts, we can assume that, Ukraine does not have a significant technical and economic potential. In order to improve the technical and economic potential, the Ukrainian electricity market should achieve the regulatory independence (IEA, 2012). At the moment, the state is the main shareholder in the majority of generating and distribution companies. The Ukrainian electricity market is liberalized only for the sector of electricity generation, but not for the distribution sector. According to the NERC a complete liberalization of the electricity market is expected for 2015 (Tsarenko, 2008; DTEK, 2011). Ukraine plans to reform the market structure, by establishing a direct contact between suppliers and consumers. According to the order # 504/ 2011 by the President of Ukraine, the national plan for economic reforms for 2010-2014 includes the development and introduction of an incentive pricing methodology (DTEK, 2011).

Therefore, the purpose of the current experiment is to determine the responsiveness of electricity consumers to price signals. To represent the households' income polarization problem, which exists in the Ukrainian economy, the participants of the experiment will be divided into two income groups. The households' income levels and rates for electricity tariffs used in the experiment are proportional to the existing rates, and represent the current situation on the Ukrainian electricity market.

5. Analysis of consumers behaviour under different price policies

5.1. ***Purpose and hypotheses of the experiment***

The current experiment is an experiment on decision making processes on the electricity market.

The experiment is designed to test the responsiveness of consumers to price signals. The behavior of different income level consumers is analyzed under three different price policies: fixed price (FP), time-of-use (TOU) and real time pricing (RTP). Under each price policy participants decide about the quantity of electricity they want to consume. In the baseline framework they decide under a fixed price policy. The Ukrainian electricity market was taken as a reference.

The electricity market in Ukraine is set with a fixed price structure, where consumers face constant predetermined electricity prices. In the current experiment, the fixed retail price for consumers is 3, 35 experimental currency units (ECU). This price reflects the current retail price in the Ukrainian electricity market.

The other two price policies, used in the experiment are two different dynamic pricing schemes. In the current experiment the problem of inefficient energy consumption is elaborated. One of the negative factors of inefficient energy consumption is a high demand for electricity in peak time. Therefore, the purpose of the current experiment is to diminish the load of electricity in peak time by introducing dynamic tariffs for electricity. Table 12 presents expected changes in the consumers' demand. The optimal level of electricity consumption was determined for each price policy.The optimum (expected) consumption level is defined as the maximum number of kWh-units, at which consumers get benefits. Therefore, it was profitable to consume electricity as long as consumers' benefits are higher or equal to the price they need to pay for it.

Table 12: Expected changes in the electricity consumption

Price policy	Time period	Expected electricity consumption		Expected changes in the consumption under dynamic tariffs
		Optimum (kWh-Units)	*% share*	
FP	*Off-peak*	24	48,98%	-
	Peak	25	51,02%	-
	Total	***49***	**100,00%**	**-**
TOU	*Off-peak*	56	94,92%	133,33%
	Peak	3	5,08%	-88,00%
	Total	***59***	**100,00%**	**20,41%**
RTP	*Off-peak*	53	89,83%	120,83%
	Peak	6	10,17%	-76,00%
	Total	***59***	**100,00%**	**20,41%**

It is important to mention that the dynamic tariffs, which are introduced in the experiment, differ not only in their design, but also in their intensity for peak load reduction.

Since under the FP policy no incentives are introduced, it is expected that the majority of electricity will be consumed at peak time. Under the TOU tariff, where price incentives are introduced, the participants will get the highest benefit if they will consume only 5, 08 % at peak time and 94, 92 % at off-peak (night and semi-peak) time. In contrast under RTP, the consumers' benefit will be the highest if they consume 10, 17 % at peak time and 89, 83 % at off-peak time. Therefore, it is expected that the TOU rate has a higher intensity for peak load reduction than RTP.

It is expected, that under both dynamic tariffs, the total electricity consumption will increase for 20, 41%. DR programs lead to efficient energy consumption and conservation, but they do not imply direct conservation. A "conservation effect" is observed when the total electricity consumption is reduced (King & Delurey, 2005). DR programs lead to a reduction of electricity consumption in some period of time, or to a complete shifting of consumption to other times. Compared to conservation programs, which are targeting to reduce the overall consumption, DR programs are more loyal to the consumer. During the implementation of demand response programs, some moments of conservation could occur. For example, it can happen, when consumers do not shift their consumption to cheaper periods of time, but just diminish their consumption in expensive time (King & Delurey, 2005).

Therefore, it is not expected that DR programs will lower the total electricity demand.

Moreover, since it is expected that the income level has no impact on the consumers' responsiveness, the expected changes in the electricity usage are equal for both income groups.

To answer the research question, this experiment is used to test three following hypotheses:

Hypothesis 1:

Subjects respond to incentives, i.e. when the price regime changes from FP to either TOU or RTP, subjects shift their consumption from peak to semi-peak and night time.

Hypothesis 2:

Subjects respond to the imposed incentives and they reduce their consumption at peak time at the higher rate when the price regime changes from FP to TOU than when it changes from FP to RTP.

Hypothesis 3:

Subjects respond to incentives regardless of their income, i.e. they respond to changes in the price regime equally in both treatments.

5.2. ***Experimental design***

There were no special requirements for the participants, and therefore the participants of the experiment were randomly chosen subjects. The experiment was programmed in z-Tree software (Fischbacher, 2007) and was executed in the Vienna Center for Experimental Economics (VCEE), University of Vienna.

Subjects were randomly and anonymously divided into two income groups: low income group and high income group. Each income group consisted of 8 subjects. All participants had an initial level of an endowment. The endowment level of the low income group was 800 experimental currency units (ECU), while the endowment level of the high income group was 1200 ECU. The participants of the experiment represented consumers, who needed to arrange their daily electricity consumption. The sale of electricity occurred in a single-side market, where the electricity supply was simulated by the computer. Under each of the three price policies, electricity was sold over three time periods:

- Night *(from 23:00-07:00)*
- Semi-peak *(from 07:00-8:00) (from 11:00-20:00)(from 22:00-23:00)*
- Peak *(from 08:00-11:00) (from 20:00-22:00)*

Three different periods represented peak, off-peak and valley times of energy usage.
The subjects had 15 tasks, under which they needed to decide the quantity of electricity they want to consume at each of the three periods in order to maximize their payoff. The tasks for participants were given in random order, but can be grouped into three different price policies: fixed price, time-of-use and real time pricing. The tasks in the experiment represented different electricity appliances which had different levels of power capacity.
The participants' final payoff was equal to a randomly chosen task payoff. The task payoff was calculated on the following way:

Task payoff = *Endowment+ Benefit − Costs*

The benefits in the experiment were represented through a declining marginal utility function, which characterized how consumers value electricity consumption. The benefits were provided by electricity use and depended on the quantity of consumed electricity. Benefits were always the highest at peak time, and declined at semi-peak and night time.
Costs per unit of electricity consumption were calculated in different ways, according to the different price policies:

Fixed tariff

Under the fixed tariff, the hourly price for electricity remained the same within a day, regardless of the consumption period. Costs per unit of the electricity consumption were calculated as:
Costs per unit of the electricity consumption = *3, 35* power capacity of the electricity appliance.*
An example of one of the tasks, given to participants under fixed tariff is presented in Appendix 1.

Time-of-use tariff

Under the time-of-use tariff, the hourly price for electricity varied across three periods of a day (night, semi-peak, peak), but remained the same within an each period. To compute the electricity price under the TOU tariff the following multi tariff coefficients were applied:

Table 13: Multi tariff coefficients for the TOU tariff

Electricity consumption	*EXU per unit of consumption*		
	Night (*from 23:00-07:00*)	**Day (from 07:00-23:00)**	
		Semi-peak (*from07:00-8:00*) (*from 11:00-20:00*) (*from 22:00-23:00*)	**Peak** (*from 08:00-11:00*) (*from 20:00-22:00*)
Multi tariff coefficients	0,4	1	1,5

The price for electricity under the TOU tariff was calculated by multiplying a fixed retail tariff (3, 35 ECU) by a corresponding dynamic coefficient.
Therefore, costs per unit of electricity consumption were calculated as:
Costs per unit of electricity consumption = *3, 35* corresponding multi tariff coefficient* power capacity of the electricity appliance*
Therefore, the electricity price at night time was 60 % lower compared to the price valid under the fixed tariff. The price at semi-peak time was the same as under the fixed tariff, while the price during peak time was 50 % higher than under the fixed tariff.
An example of one of the tasks, given to participants under the TOU tariff is presented in Appendix 2

Real time pricing

Under real time pricing, prices for electricity varied hourly and represented the hourly price variations on the wholesale electricity market. As at the TOU tariff, the price for electricity was the highest during peak time, at medium level in semi-peak time and at the lowest level during night time.
An example of one of the tasks, given to participants under real time pricing is presented in Appendix 3.

In the experiment a neutral frame was used, therefore the term “electricity” was replaced by the term “imaginary good”. As a result, instead of consuming one kWh per hour, subjects consumed one unit of “imaginary good” per hour.
The participants were able to consume maximum one unit of electricity per hour. Therefore, it is 24 units per day (8 units at night time; 11 units at semi-peak time and 5 units at peak time).

The participants received instructions (Appendix 4 &5), where main features of the experiment were described. The instructions for both groups differed only in the amount of the initial endowment. Subjects had 10 minutes to read the instruction and to ask any questions they had. The participants had 2 minutes per task to make their decisions. However, after the expiration of 2 minutes, participants still were able to make their decision in time they needed. Participants were paid privately at the end of the experiment. The average earning was 14€ per hour. The experiment lasted about 50 minutes.

5.3. *Data analysis and main results*

Result1: *Subjects responded to incentives, i.e. when the price regime had changed from FP to TOU and RTP, subjects shifted their consumption from peak to (semi-peak and night) time.*

Table 14 visualizes the results of the T-test comparing the average actual electricity consumption under different price policies.

Table 14: Comparison of electricity consumption by price policy

Price policy	Time period	Average electricity demand (kWh-Units)				Mean difference to the FP	T- test
		Actual	*% share*	*Optimal*	*% share*		
FP	*Night*	6,50	17,69%	2	4,08%	-	-
	Semi-peak	15,06	40,98%	22	44,90%	-	-
	Off-peak	21,56	58,67%	24	48,98%	-	-
	Peak	15,18	41,31%	25	51,02%	-	-
	Total	***36,75***	**100,00%**	***49***	**100,00%**	**-**	**-**
TOU	*Night*	19,93	48,76%	36	61,02%	13.437 (+)	3,71 (**)
	Semi-peak	14,12	34,55%	20	33,90%	0.937 (-)	-0,58
	Off-peak	34,05	83,31%	56	94,92%	12,5 (+)	2,61 (*)
	Peak	6,81	16,66%	3	5,08%	8.375 (-)	-4,7 (***)
	Total	***40,87***	**100,00%**	***59***	**100,00%**	**4.125 (+)**	**1,06**
RTP	*Night*	19,18	44,87%	32	54,24%	12.687 (+)	4,74 (***)
	Semi-peak	15,43	36,09%	21	35,59%	0.375 (+)	0,29
	Off-peak	34,61	80,96%	53	89,83%	13,062 (+)	4,4 (***)
	Peak	8,12	18,99%	6	10,17%	7.062 (-)	3,75 (***)
	Total	***42,75***	**100,00%**	***59***	**100,00%**	**6.00 (+)**	**2,29 (*)**

Source: data from the laboratory experiment

The observed data indicate that consumers are highly sensitive to different price policies. The overview of the energy demand shows that under the FP policy, the major part of electricity was consumed at the off-peak time (58, 67 %). Nevertheless, a significant part of electricity (41, 31 %) was consumed at peak time. This result confirms the expectation, that in case of no incentives, a significant part of electricity will be consumed at the peak time.

In contrast, under both dynamic tariffs the share of energy consumed at peak time was significantly smaller. Compared to the fixed price, consumers reduced their consumption at the peak time. Under both dynamic tariffs the level of peak load reduction was statistically significant. The share of the electricity consumed at the semi-peak time has decreased under dynamic tariffs. However, the level of reduction was statistically insignificant. This result does not contradict to the expectations. It was expected that the consumption at the semi-peak time should decline under dynamic tariffs. Overall, under dynamic tariffs, the electricity consumption at the off-peak (night and semi- peak) time increased, while the peak consumption has decreased. Changes in peak and off- peak consumption were statistically significant. Therefore, this finding corresponds to the first hypothesis.

In spite under both dynamic tariffs consumers responded to price signals and shifted their consumptions from more to less expensive time periods, we can observe a significant deviation from the expected optimal behaviour.

Table 15 represents the deviation rate of the actual consumption from the expected (optimum) level.

Table 15: Deviation of the actual consumption from the optimal levels

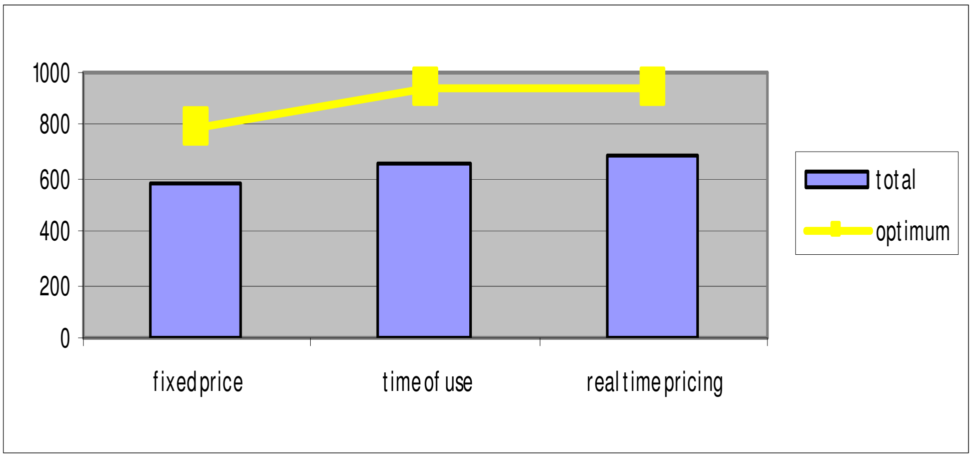
Price policy	Time period	Average electricity demand				% of deviation from the optimal level	Mean difference	T- test
		Actual	*% share*	*Optimum*	*% share*			
FP	*Night*	6,50	17,69%	2	4,08%	225,00%	4,5 (+)	3,15 (**)
	Semi-peak	15,06	40,98%	22	44,90%	-31,55%	6,93 (-)	-3,47(**)
	Off-peak	21,56	58,67%	24	48,98%	-10,17%	2,43 (-)	-0,74
	Peak	15,18	41,31%	25	51,02%	-39,28%	9,81 (-)	-6,26 (****)
	Total	***36,75***	**100,00%**	***49***	**100,00%**	**-25,00%**	***12,25 (-)***	***-3,13 (**)***
TOU	*Night*	19,93	48,76%	36	61,02%	-44,64%	16,06 (-)	-5,56 (****)
	Semi-peak	14,12	34,55%	20	33,90%	-29,40%	5,87 (-)	-3,26 (***)
	Off-peak	34,05	83,31%	56	94,92%	-39,20%	21,93 (-)	-4,93 (***)
	Peak	6,81	16,66%	3	5,08%	127,00%	3,81 (+)	3,67(**)
	Total	***40,87***	**100,00%**	***59***	**100,00%**	**-30,73%**	***18,12 (-)***	***-3,79 (****)***
RTP	*Night*	19,18	44,87%	32	54,24%	-40,06%	12,81 (-)	-5,24 (****)
	Semi-peak	15,43	36,09%	21	35,59%	-26,52%	5,65 (-)	-2,66 (*)
	Off-peak	34,61	80,96%	53	89,83%	-34,70%	18,37 (-)	-4,39 (***)
	Peak	8,12	18,99%	6	10,17%	35,33%	2,12 (+)	2,11
	Total	***42,75***	**100,00%**	***59***	**100,00%**	**-27,54%**	***16,25 (-)***	***-3,38 (**)***

Source: data from the laboratory experiment

The observed data indicate, that under both dynamic tariffs, participants have exceeded the optimum level of peak consumption. Therefore, the actual peak load reduction rate was less than expected. Nevertheless, under RTP the deviation of the actual peak consumption from the expected rate was statistically insignificant. Under RTP, participants at peak time consumed 35 % more electricity than the optimum level would be, while under TOU participants exceeded the optimal peak consumption by 127%. The better performance at the peak time under RTP could be explained by the difference among tariffs in their incentives for the peak load reduction. It was optimal to consume 5% of electricity at the peak time under TOU tariff, while under RTP the optimum peak consumption was two times higher. Therefore, taking into consideration that under both tariffs participants have exceeded the optimal level of peak consumption, their actual consumption at the peak time was closer to the optimal level under RTP. Since the shifting rate from peak to off-peak time had been less than expected, participants consumed less electricity at the off-peak time than the optimum level would be. Under the TOU tariff, 95 % of electricity should be consumed at the off-peak time. In contrast, the actual off-peak consumption amounted to 83%. Under RTP, 90% of electricity was expected to be consumed at the off-peak time, while the actual off-peak consumption amounted to 81%. As at the peak time, the off-peak consumption was closer to the optimal level under RTP. However, the deviation from the optimal level was statistically significant under both dynamic tariffs.

Under both dynamic tariffs the aggregate consumption has increased. However, under all price policies consumers consumed less electricity than it had been expected.

Figure 21: Total electricity consumption (kWh-Units)



Source: data from the laboratory experiment

The level of deviation of the aggregate consumption from the optimal level was the smallest under FP policy (25%). Comparing the dynamic tariffs, the aggregate consumption was closer to the optimum under RTP. The level of aggregate consumption deviation was 27% under RTP and 31% under TOU. Nevertheless, the deviation of the actual aggregate consumption from the optimum level was statistically significant under all price policies (Table 15).

Result 2: *Subjects responded to the imposed incentives. Consumers reduced their consumption at peak time at a higher rate when the price regime had changed from FP to TOU than when it had changed from FP to RTP.*

Table 16 presents the comparison of consumer's response under TOU and RTP tariffs.

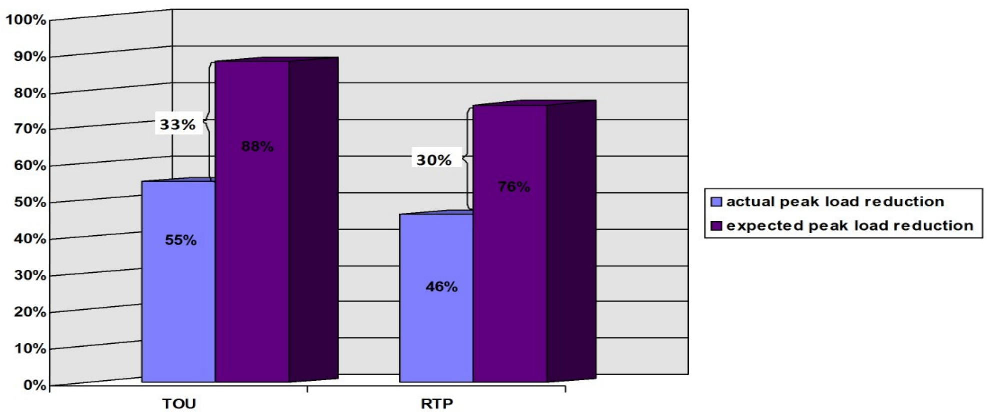
Table 16: Comparison of the demand response under TOU and RTP tariffs

Price policy	Time period	Average electricity consumption (kWh-Units)		Changes in the electricity demand		Mean difference	T- test
		Actual	Optimum	Actual	Optimum		
FP	off-peak	21,56	24	-	-	-	-
	peak	15,18	25	-	-	-	-
	Total	36,75	49	-	-	-	-
TOU	off-peak	34,05	56	57,93%	133,33%	-	-
	peak	6,81	3	-55,14%	-88,00%	-	-
	Total	40,87	59	11,21%	20,41%	-	-
RTP	off-peak	34,61	53	60,53%	120,83%	-	-
	peak	8,12	6	-46,51%	-76,00%	-	-
	Total	42,75	59	16,33%	20,41%	-	-
TOU-RTP	off-peak	-	-	1,64%	-5,36%	0,56 (-)	-0,17
	peak	-	-	19,24%	100,00%	1,31 (-)	-2,37 (*)
	Total	-	-	4,60%	0,00%	1,87 (-)	-0,53

Source: data from the laboratory experiment

The observed data indicate, that the peak load reduction was higher under TOU tariff. The difference in the peak load reduction among dynamic tariffs was statistically significant at the 95 % confidence level. This finding corresponds to the expectation of the second hypothesis. The peak load was reduced by 55 % under TOU tariff, while under RTP the peak consumption was reduced by 46 %. The results on peak load reduction were statistically significant for both dynamic tariffs (Table 14).

Figure 22: Actual and expected peak load reduction by price policy



Source: data from the laboratory experiment

The higher impact of the TOU tariff on the peak load reduction does not contradict to the expectations. By the design of the experiment the incentives for peak load reduction were higher under TOU. However, due to the deviation from the optimal behaviour, the peak load reduction was lower than had been expected under both dynamic tariffs. Compared to the TOU tariff, the deviation from the expected peak load reduction was lower under RTP.

It was expected that dynamic tariffs would raise the aggregate consumption level for 20, 41 %. However, the actual raise of aggregate consumption was less than it had been expected. The actual aggregate consumption has increased by 11% under TOU tariff, and by 16% under RTP (Table 16).

Taking into consideration that under TOU tariff, the raise of the aggregate consumption was lower and the peak load reduction was higher, it can be assumed that the TOU tariff has a higher impact on the reduction of inefficient electricity consumption.

Result 3: *Subjects responded to incentives regardless of their income, i.e. they have responded to changes in the price regime equally in both treatments.*

Table 17: The difference in the demand response among income groups

Price policy	Time period	Average electricity demand (kWh-Units)						Mean difference between income groups	T- test
		Actual				*Optimum*			
		kWh-Units		*% share*					
		High	Low	High	Low	kWh-Units	*% share*		
FP	*Night*	*6,12*	*6,87*	17,44%	17,91%	2	4,08%	0,75 (-)	-0,25
	Semi-peak	*13,87*	*16,25*	39,50%	42,35%	22	44,90%	2,37 (-)	-0,58
	Off-peak	*19,99*	*23,12*	56,94%	60,26%	24	48,98%	3,12 (-)	-0,49
	Peak	*15,12*	*15,25*	43,06%	39,74%	25	51,02%	0,12 (-)	-0,03
	Total	***35,12***	***38,37***	**100,00%**	**100,00%**	**49**	**100,00%**	**3,25 (-)**	***-0,40***
TOU	*Night*	*22,25*	*17,62*	49,72%	47,64%	36	61,02%	4,62 (+)	0,79
	Semi-peak	*15,37*	*12,87*	34,36%	34,80%	20	33,90%	2,50 (+)	0,68
	Off-peak	*37,62*	*30,49*	84,08%	82,44%	56	94,92%	7,12 (+)	0,79
	Peak	*7,12*	*6,50*	15,92%	17,56%	3	5,08%	0,62 (+)	0,29
	Total	***44,75***	***37,00***	**100,00%**	**100,00%**	**59**	**100,00%**	**7,75 (+)**	**0,80**
RTP	*Night*	*20,37*	*18,00*	46,84%	42,85%	32	54,24%	2,35 (+)	0,47
	Semi-peak	*15,00*	*15,87*	34,48%	37,80%	21	35,59%	0,87 (-)	-0,20
	Off-peak	*35,37*	*33,87*	81,32%	80,65%	53	89,83%	1,5 (+)	0,17
	Peak	*8,12*	*8,12*	18,68%	19,35%	6	10,17%	0,00	0
	Total	***43,50***	***42,00***	**100,00%**	**100,00%**	**59**	**100,00%**	**1,50 (+)**	**0,15**

Source: data from the laboratory experiment

The observed data show, that the difference in demand response between two income groups is statistically insignificant. This finding supports to the third hypothesis. Consumers of both income groups have shifted their consumption from the more expensive peak time to the less expensive semi-peak and night time. During the introduction of dynamic tariffs, consumers of both income groups increased their consumption at the off-peak time and decreased the peak consumption. Compared to the FP, under TOU tariff the share of electricity consumed at the peak time has declined and amounted 15, 92 % and 17, 56% for high- and low- income group respectively. Under RTP the difference in the peak consumption among income groups was even smaller. The high income group consumed 18, 68 % at the peak time, while the low income group consumed 19, 35 %. As expected, the peak load reduction was higher under TOU tariff in both income groups. In spite the difference in demand response was insignificant among income groups, the high income group significantly deviated from the expected optimal behaviour. The deviation of the actual consumption from the expected levels among income groups is presented in Table 18. Under the RTP policy, the amount of electricity consumed at the peak time was the same for both income groups. Therefore, the deviation of the actual peak consumption from the optimum level was statistically insignificant for both income groups. At the off-peak time consumers of both income groups consumed less electricity than it had been expected. The deviation of the actual off-peak consumption from the expected was statistically significant for both income groups. One reason for the under consumption at the off- peak time is that, consumers exceeded the optimal consumption level at the peak time and did not shift their consumption at the expected rate. The second reason is that under all price policies the aggregate consumption of both income groups was less than it had been expected (Figure 23). Under the TOU tariff, the deviation of the actual peak consumption from the optimum was statistically insignificant for the low-income group. The high-income group exceeded the peak consumption by 137% and the deviation was statistically significant at the 95 % confidence level. The deviation of the actual off-peak consumption amounted to 45, 55% for the low income group and 32, 82% for the high income group. The off-peak deviation was statistically significant for both income groups (Table 18).

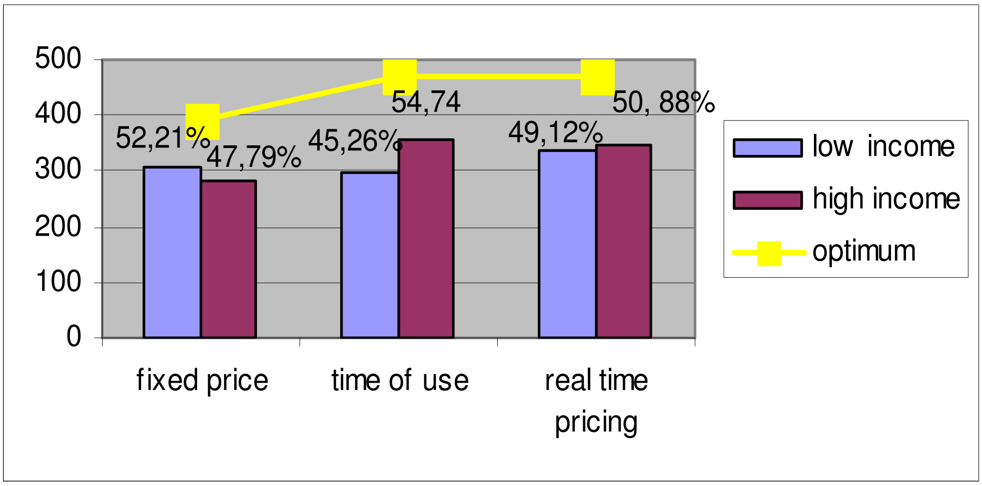
Table 18: Deviation from the optimal behaviour by income group

Income group	Price policy	Time period	Average electricity demand (kWh-Units)				% of deviation from the optimal level	Mean difference	T-test
			Actual	% share	Optimal	% share			
High	FP	*Night*	6,12	17,44%	2	4,08%	206,00%	4,12	2,16
		Semi- peak	13,87	39,50%	22	44,90%	-36,95%	8,12 (-)	-2,88 (*)
		Off-peak	19,99	56,94%	24	48,98%	-16,71%	4,00 (-)	-0,97
		Peak	15,12	43,06%	25	51,02%	-39,52%	9,87 (-)	-3,97(**)
		Total	**35,12**	**100,00%**	**49**	**100,00%**	**-28,33%**	**13,87 (-)**	**-2,47 (**)**
	TOU	*Night*	22,25	49,72%	36	61,02%	-38,19%	*13,75 (-)*	-3,28 (*)
		Semi- peak	15,37	34,36%	20	33,90%	-23,15%	*4,62 (-)*	-1,66
		Off-peak	37,62	84,08%	56	94,92%	-32,82%	*18,37 (-)*	-2,74 (*)
		Peak	7,12	15,92%	3	5,08%	137,33%	*4,12 (+)*	3,16 (*)
		Total	**44,75**	**100,00%**	**59**	**100,00%**	**-24,15%**	***14,25 (-)***	**-1,94**
	RTP	*Night*	20,37	46,84%	32	54,24%	-36,34%	*11,62 (-)*	-3,67 (**)
		Semi- peak	15,00	34,48%	21	35,59%	-28,57%	*6 (-)*	-2,35 (*)
		Off-peak	35,37	81,32%	53	89,83%	-33,26%	*17,62 (-)*	-3,40 (*)
		Peak	8,12	18,68%	6	10,17%	35,33%	*2,12 (+)*	2,27
		Total	**43,50**	**100,00%**	**59**	**100,00%**	**-26,27%**	***15,5 (-)***	**-2,77 (*)**
Low	FP	*Night*	6,87	17,91%	2	4,08%	243,50%	4,87	2,16
		Semi- peak	16,25	42,35%	22	44,90%	-26,14%	5,75 (-)	-1,94
		Off-peak	23,12	60,26%	24	48,98%	-3,67%	0,87 (-)	-0,18
		Peak	15,25	39,74%	25	51,02%	-39,00%	9,75 (-)	-4,67 (**)
		Total	**38,37**	**100,00%**	**49**	**100,00%**	**-21,69%**	**10,62 (-)**	**-1,84**
	TOU	*Night*	17,62	47,64%	36	61,02%	-51,06%	*18,37 (-)*	-4,51 (**)
		Semi- peak	12,87	34,80%	20	33,90%	-35,65%	*7,12 (-)*	-2,98 (*)
		Off-peak	30,49	82,44%	56	94,92%	-45,55%	*25,5 (-)*	-4,24 (**)
		Peak	6,50	17,56%	3	5,08%	116,67%	*3,5 (+)*	2,05
		Total	**37,00**	**100,00%**	**59**	**100,00%**	**-37,29%**	***22 (-)***	**-3,49 (*)**
	RTP	*Night*	18,00	42,85%	32	54,24%	-43,75%	*14 (-)*	-3,59 (**)
		Semi- peak	15,87	37,80%	21	35,59%	-24,43%	*5,12 (-)*	-1,47
		Off-peak	33,87	80,65%	53	89,83%	-36,09%	*19,12 (-)*	-2,76 (*)
		Peak	8,12	19,35%	6	10,17%	35,33%	*2,12 (+)*	1,14
		Total	**42,00**	**100,00%**	**59**	**100,00%**	**-28,81%**	***17 (-)***	**-2,06**

The analysis of the aggregate consumption among income groups indicates that, the low income group has consumed an insignificantly smaller amount of electricity (48, 75 %) compared to the high income group (51, 25%). The insignificant difference in the load profile among income groups (Table 17) suggests that both income groups had the same ability to shift their load.

Figure 23 presents changes in the aggregate demand among income groups.

Figure 23: Changes in the electricity demand by income group (kWh-Units)



Source: data from the laboratory experiment

The changes in the aggregate consumption were ambiguous among income groups. Under the FP policy, the low income group has consumed by 4, 42 % more electricity, than the high income group. Under both dynamic tariffs, consumers with a high income have consumed more electricity than the low income consumers. Compared to the FP policy, the consumption level of the high income group has increased by 27, 42% under TOU tariff and by 23, 86 % under RTP (Table 19). The energy use of the low income group has diminished by 3, 58 % under TOU tariff, and has increased by 9, 45% under RTP.

Table 19 presents the actual and expected changes in the electricity demand by income group

Table 19: Expected and actual changes in the electricity demand by income group

Income group	Price policy	Time period	Average electricity consumption (kWh-Units)		Changes in the electricity demand		Mean difference compare to the FP	T-test
			Actual	Optimum	Actual	Optimum		
High	FP	*Off-peak*	19,99	24,00	-	-	-	-
		Peak	15,12	25,00	-	-	-	-
		Total	35,12	49,00	-	-	-	-
	TOU	*Off-peak*	37,62	56,00	88,19%	133,33%	17,62 (+)	2,63 (*)
		Peak	7,12	3,00	-52,91%	-88,00%	8,00 (-)	-3,56 (**)
		Total	44,75	59,00	27,42%	20,41%	9,63 (+)	1,96
	RTP	*Off-peak*	35,37	53,00	76,94%	120,83%	15,37 (+)	3,56 (**)
		Peak	8,12	6,00	-46,30%	-76,00%	7,00 (-)	-2,68 (*)
		Total	43,50	59,00	23,86%	20,41%	8,38 (+)	2,51 (*)
Low	FP	*Off-peak*	23,12	24,00	-	-	-	-
		Peak	15,25	25,00	-	-	-	-
		Total	38,37	49,00	-	-	-	-
	TOU	*Off-peak*	30,49	56,00	31,88%	133,33%	7,37	1,08
		Peak	6,50	3,00	-57,38%	-88,00%	8,75 (-)	3,00 (*)
		Total	37,00	59,00	-3,57%	20,41%	1,37 (-)	-0,24
	RTP	*Off-peak*	33,87	53,00	46,50%	120,83%	10,75 (+)	2,56 (*)
		Peak	8,12	6,00	-46,75%	-76,00%	7,13 (-)	-2,47 (*)
		Total	42,00	59,00	9,46%	20,41%	3,63 (+)	0,88 (*)

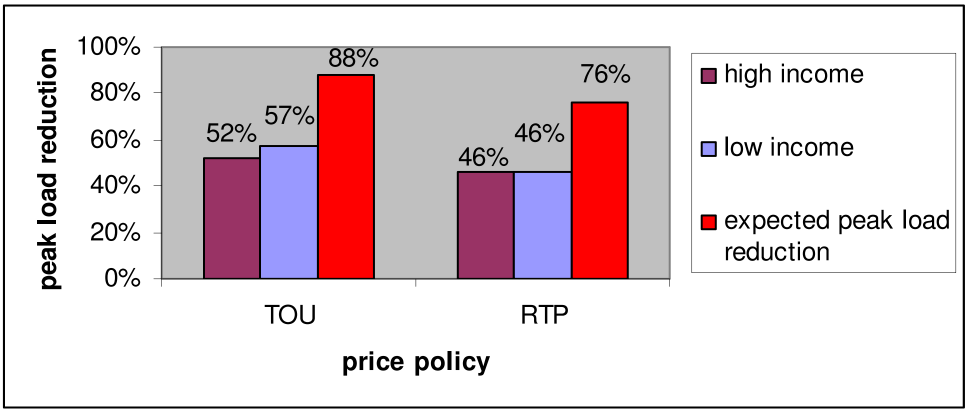
Source: data from the laboratory experiment

The observed data indicate, that the actual peak load reduction was significantly lower than it had been expected in both income groups. In both income groups the peak load reduction was higher under TOU tariff. This finding does not contradict to the expectations. In spite, the difference between two income groups in the peak load reduction was statistically insignificant (Table 17), we can observe that the low income group was more price responsive. Under the TOU tariff the peak load reduction of the low income group amounted to 57, 38%, while the peak load reduction of the high income group amounted to 52, 91 %. The peak load reduction was smaller than expected, however, the low income group has deviated less from the optimum level.

Under RTP, the peak load reduction was also slightly higher in the low income group. The low income group reduced the peak consumption by 46, 75%, while the high income group diminished their consumption by 46, 30 %.

Figure 24 presents expected and the actual level of the peak load reduction by income groups.

Figure 24: Level of the peak load reduction by income group



Source: data from the laboratory experiment

Compared to the TOU tariff, the deviation from the expected peak load reduction was less under RTP for both income groups.

Adding together all these facts we can assume that consumer's income level does not influence the willingness to respond to price signals. The difference in the price response was statistically insignificant among income groups. However, under dynamic tariffs the consumption behaviour of low-income consumers was closer to the expected optimum level.

6. Conclusion

The main purpose of this study was to estimate the possibility of implementing price-based demand response programs in low-income countries. The observation of different electricity markets shows that demand response programs are widely used in the United States and some European countries to reduce the high demand for electricity in peak hours. However, the quantity of operating demand response programs in countries with low income is insignificant. The main factor that deters the introduction of DR programs into those electricity markets is the low level of tariffs. The current research was based on the Ukrainian electricity market, where residential tariffs for electricity cover only 60% of the costs for its generation. Together with a low tariff levels, this study has covered the problem of the income polarization that characterizes the Ukrainian economy. Therefore, in order to estimate the possibility to implement DR programs into the Ukrainian electricity market, it was important to answer for the following question: how do consumers with different income levels respond to dynamic tariffs for electricity?

The data from the experiment showed that, in spite of low energy prices relative to the existing income levels, consumers respond to price signals. Consumers reduced their consumption in peak hours, and shifted their consumption to the off-peak time. This finding supports to the first hypothesis. The peak load reduction was 55% at the TOU tariff and 46 % under RTP. The peak load reduction was statistically significant at the 95% confidence level. Nevertheless, under doth dynamic tariffs consumers deviated from the expected optimal behaviour. Due to this deviation, the peak load reduction was lower than it had been expected. Compared to the TOU tariff, the deviation was lower under RTP.

The result of the experiment also shows that, consumers respond to price signals according to the imposed incentives. By the design of the experiment, the TOU tariff had a higher impact on peak load reduction. The comparison of the actual consumption shows that the peak load reduction was higher under TOU tariff and the difference between dynamic tariffs was statistically significant. This finding supports to the second hypothesis.

Dynamic tariffs have led to an increase of the aggregate consumption. The aggregate demand has increased by 11% under TOU tariff, and by 16 % under RTP. Since the reduction of the total electricity consumption was not a target of the current experiment, this finding does not contradict to the expectations. Nevertheless, under all price policies consumers have consumed less electricity than it had been expected. The aggregate consumption among income groups varied under different price policies. However, totally, the low-income group consumed less electricity (48, 75%) compared to the high-income group (51, 25%). The small difference in the electricity load suggests that consumers of both income groups had the same "chances" to respond to price signals.

The comparison of demand response among income groups indicates that the difference in the peak load reduction was statistically insignificant. However, the low income group was more responsive to price signals and has diminished their peak consumption at a higher rate. The average peak load reduction of the low-income group amounted to 57 % under TOU tariff and to 47 % under RTP. The average peak load reduction of the high-income group was 53% under TOU and 46% under RTP. Nevertheless, the difference in the demand response among income groups appeared to be statistically insignificant. These results confirm the third hypothesis. Therefore, contrary to the arguments about the inability of low-income consumers to respond to price signals, the result of the current experiment shows that low-income consumers shift their consumption in response to price signals. Under dynamic tariffs, the deviation of low-income consumers from the expected optimal behaviour was statistically insignificant. Therefore, we can assume that consumers' income level does not influence the willingness to respond to price signals. The peak load reduction for both income groups was higher under TOU tariff.

Adding together all these facts we can assume that, in spite tariffs for electricity are low, consumers respond to price signals and shift their consumption. Moreover, consumers of both income levels equally respond to price signals. However, it is problematic to answer, whether dynamic tariffs are applicable for low-income countries. It should be taken into consideration that the current results are obtained from a small sample of participants. Conclusions of the current experiment are based on the observation of the consumption behaviour of 16 consumers. Therefore, a bigger sample size may give different results.

In the current experiment a neutral frame was used. The neutral frame was used in order to avoid a "framing effect". Therefore, it is also important to understand whether the individual behaviour in the laboratory experiment provides a reliable indicator for the consumer's behaviour in the naturally occurring environment. Harison et al. (2007) examined the impact of the "neutral frame" on the participant's level of risk aversion. Their results indicate that in the presence of artificial rewards, results from a laboratory experiment are reliable, when the neutral counterpart has a minimum uncertainty. Since in the current experiment, individual payoffs were not affected by the decisions of other participants, there were no uncertainties in outcomes. Therefore, we may conclude that the current results are a good indicator for the consumer's behaviour in the natural environment.

However, it needs to be taken into consideration, that establishing of DR programs in low-income countries might be threatened due to high costs. The implementation of DR programs requires investments for smart meters and several other upgrades to the electric grid. The observation of the Ukrainian energy market has shown that costs for smart meters significantly outweigh costs for standard meters. Therefore, the investments for the necessary equipment lower the possibility to implement DR programs in low-income countries. Due to that fact, as a further research it would be challenging to include in the experiment costs for the necessary equipment and estimate consumers' willingness to invest in costly equipment.

The other factor which affects the possibility to implement DR programs in Ukraine is the "non-payment" problem. Nevertheless, this problem was not taken into consideration in the experiment design. In order to implement DR programs into the Ukrainian electricity market the government should improve consumer's payment behaviour by implementing a system of punishment for non-payers.

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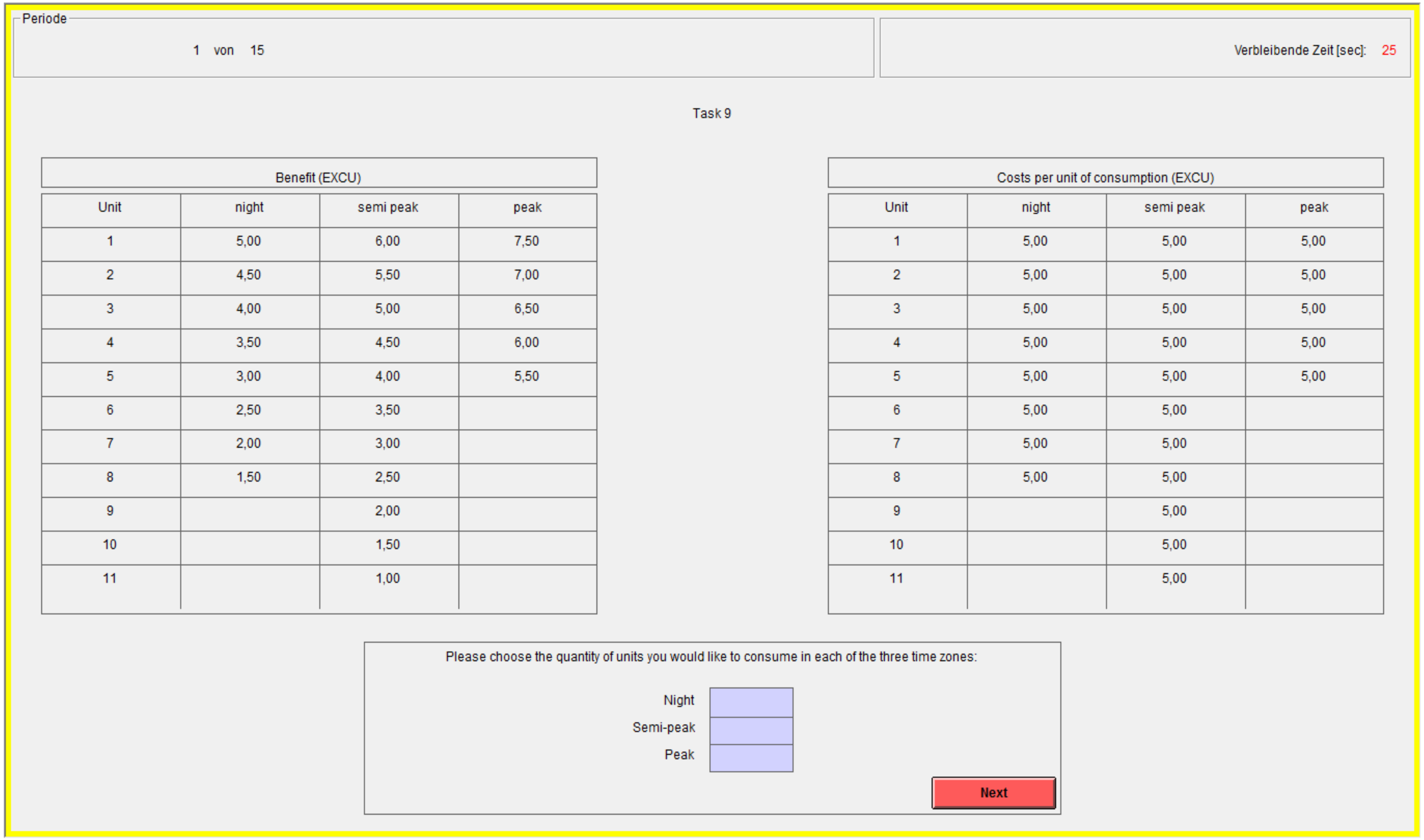
8. Appendices

8.1. *Appendix 1: Screenshot of a task under fixed price*



Periode

1 von 15

Verbleibende Zeit [sec]: 25

Task 9

Benefit (EXCU)			
Unit	night	semi peak	peak
1	5,00	6,00	7,50
2	4,50	5,50	7,00
3	4,00	5,00	6,50
4	3,50	4,50	6,00
5	3,00	4,00	5,50
6	2,50	3,50	
7	2,00	3,00	
8	1,50	2,50	
9		2,00	
10		1,50	
11		1,00	

Costs per unit of consumption (EXCU)			
Unit	night	semi peak	peak
1	5,00	5,00	5,00
2	5,00	5,00	5,00
3	5,00	5,00	5,00
4	5,00	5,00	5,00
5	5,00	5,00	5,00
6	5,00	5,00	
7	5,00	5,00	
8	5,00	5,00	
9		5,00	
10		5,00	
11		5,00	

Please choose the quantity of units you would like to consume in each of the three time zones:

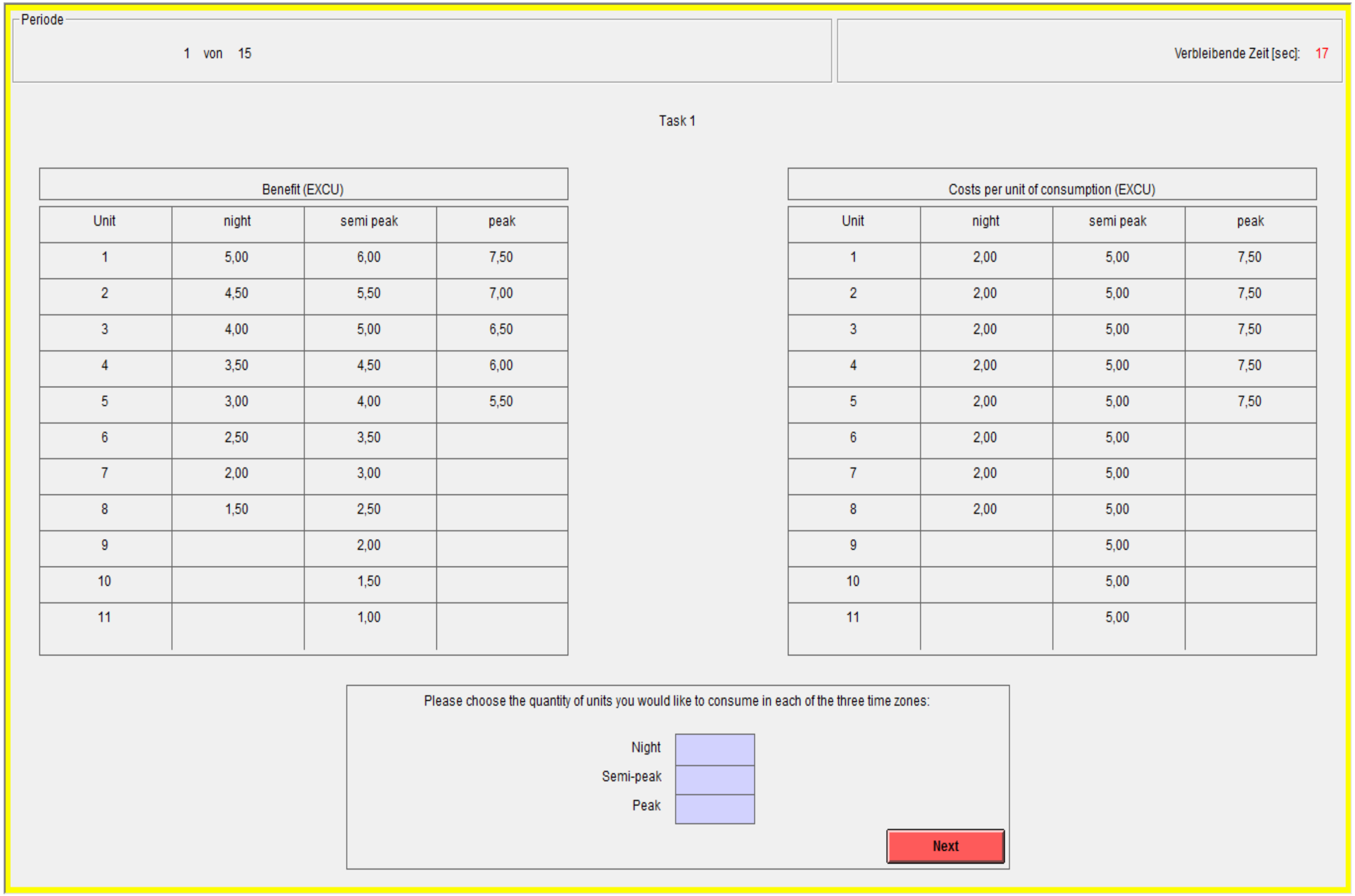
Night

Semi-peak

Peak

Next

8.2. ***Appendix 2: Screenshot of a task under TOU***



Periode

1 von 15

Verbleibende Zeit [sec]: 17

Task 1

Benefit (EXCU)			
Unit	night	semi peak	peak
1	5,00	6,00	7,50
2	4,50	5,50	7,00
3	4,00	5,00	6,50
4	3,50	4,50	6,00
5	3,00	4,00	5,50
6	2,50	3,50	
7	2,00	3,00	
8	1,50	2,50	
9		2,00	
10		1,50	
11		1,00	

Costs per unit of consumption (EXCU)			
Unit	night	semi peak	peak
1	2,00	5,00	7,50
2	2,00	5,00	7,50
3	2,00	5,00	7,50
4	2,00	5,00	7,50
5	2,00	5,00	7,50
6	2,00	5,00	
7	2,00	5,00	
8	2,00	5,00	
9		5,00	
10		5,00	
11		5,00	

Please choose the quantity of units you would like to consume in each of the three time zones:

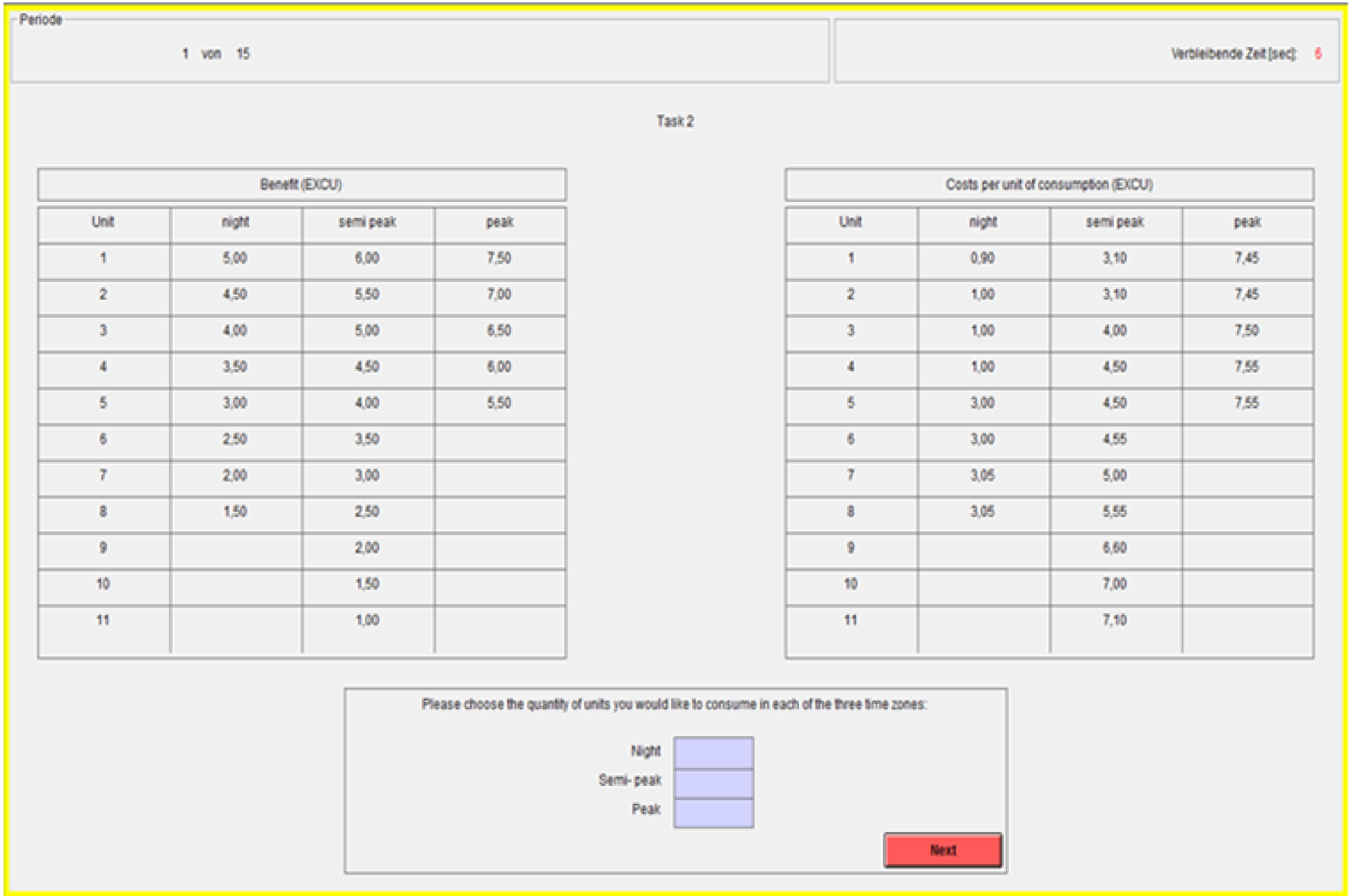
Night

Semi-peak

Peak

Next

8.3. *Appendix 3: Screenshot of a task under RTP*



8.4. *Appendix 4: Instruction for the participants of low-income group*

INSTRUCTION

GENERAL INFORMATION

You are a participant of an experiment on individual decision-making. The instruction for the experiment is simple and if you follow it carefully, you may earn a substantial amount of money. The money you earn will be paid to you privately, immediately after the experiment.

Note that this is an individual choice decision-making experiment. This means that you will make decisions on your own and your profit will not be affected by other subjects' decisions.

The experiment will consist of 15 tasks. In each task, you represent a consumer who needs to arrange his daily consumption of an imaginary good.

Each task represents one day of consumption that is divided into three time zones:

- Night *(from 23:00-07:00)*
- Semi peak *(from 07:00-08:00); (from 11:00-20:00); (from 22:00-23:00)*
- Peak *(from 08:00-11:00); (from 20:00-22:00)*

Your task is to choose how many units of good to consume during each time zone. Please note, that you are able to consume at most one unit per hour, i.e.:

- At most 8 units during night;
- At most 11 units during the semi peak;
- At most 5 units during peak.

All transactions will be in ECU (experimental currency units). You will have an endowment of 800, 00 ECU at the beginning of each task of experiment.

PROFIT CALCULATION

You may earn different amount of money depending on the choice you made. You receive a benefit from the consumption, which is varying between time zones. The benefit changes also with the quantity of your total consumption.
The payoff in every task is calculated on the following formula:

Task payoff = Endowment+ Benefit − Costs

Where,

***Benefit** is the benefits you get, from the consumption of imaginary good.*
***Costs** are the costs you pay for the consumption of imaginary good.*

The displayed screen will provide information about benefits, you can get, and costs you should pay per unit of consumption.

As your final payoff the computer will randomly choose only one *task payoff* out of the 15 tasks.
Your final payoff will be exchanged to Euro. The exchange rate is 1 Euro= 68 ECU.
When the experiment is over, you will be paid privately at the entry after showing your ID and computer number.

TIMING

The experiment will last about 60 minutes. Every task has a timeout of 2 minutes.

Please, do not communicate with other participants for the duration of the experiment. If you have any questions, please rise a hand and an assistant will come to your table.

8.5. *Appendix 5: Instruction for the participants of high-income group*

INSTRUCTION

GENERAL INFORMATION

You are a participant of an experiment on individual decision-making. The instruction for the experiment is simple and if you follow it carefully, you may earn a substantial amount of money. The money you earn will be paid to you privately, immediately after the experiment.

Note that this is an individual choice decision-making experiment. This means that you will make decisions on your own and your profit will not be affected by other subjects' decisions.

The experiment will consist of 15 tasks. In each task, you represent a consumer who needs to arrange his daily consumption of an imaginary good.

Each task represents one day of consumption that is divided into three time zones:

- Night *(from 23:00-07:00)*
- Semi peak *(from 07:00-08:00); (from 11:00-20:00); (from 22:00-23:00)*
- Peak *(from 08:00-11:00); (from 20:00-22:00)*

Your task is to choose how many units of good to consume during each time zone. Please note, that you are able to consume at most one unit per hour, i.e.:

- At most 8 units during night;
- At most 11 units during the semi peak;
- At most 5 units during peak.

All transactions will be in ECU (experimental currency units). You will have an endowment of 1200, 00 ECU at the beginning of each task of experiment.

PROFIT CALCULATION

You may earn different amount of money depending on the choice you made. You receive a benefit from the consumption, which is varying between time zones. The benefit changes also with the quantity of your total consumption.
The payoff in every task is calculated on the following formula:

Task payoff = Endowment+ Benefit − Costs

Where,

***Benefit** is the benefits you get, from the consumption of imaginary good.*
***Costs** are the costs you pay for the consumption of imaginary good.*

The displayed screen will provide information about benefits, you can get, and costs you should pay per unit of consumption.

As your final payoff the computer will randomly choose only one *task payoff* out of the 15 tasks.
Your final payoff will be exchanged to Euro. The exchange rate is 1 Euro= 68 ECU.
When the experiment is over, you will be paid privately at the entry after showing your ID and computer number.

TIMING

The experiment will last about 60 minutes. Every task has a timeout of 2 minutes.

Please, do not communicate with other participants for the duration of the experiment. If you have any questions, please rise a hand and an assistant will come to your table.

8.6. *Appendix 6: Curriculum vitae*

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Nataliya Schönleitner

Date of birth: September 2nd, 1983
Citizenship: Ukrainian
Marital status: married

Education

Master of Social and Economic Sciences

2010-2013	**University of Vienna**, Austria MSocEcSc
2009-2010	**University of Vienna**, Austria Foundation language course
2003-2005	**Kyiv National Economic University**, Ukraine Master of Economics and Entrepreneurship Specialization in Industrial Accounting and Auditing
2000-2003	**Kyiv National Economic University**, Ukraine Bachelor of Economics and Entrepreneurship

Professional experience

20.02.2008-16.10.2008	**Metso Minerals** Accountant
20.11.2006-04.01.2008	**SuncoinInvest LLC** Financier
03.04.2006-01.09.2006	**LunaPark CJSC**, ALEF Corporation Accountant

15.08.2005-02.02.2006 **DnepromashInvest, LLC**
Deputy Chief Accountant

12.07.2004-10.08.2005 **Taypan- Security Agency LLC**
Chief Accountant

01.12.2003-11.07.2004 **Taypan- Security Agency LLC**
Accountant

Additional skills and knowledge

Languages: Russian (native)
Ukrainian (native)
English (fluent)
German (C1)

Interests

Swimming, reading, traveling, cycling