Subtask 2
Time of Use Pricing for Demand Management Delivery

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Task XI: Time of Use Pricing and Energy Use for Demand Management Delivery

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IEA DSM REPORT - EXECUTIVE SUMMARY

Task XI Subtask 2

Time of Use Pricing for Demand Management Delivery

Background

End uses of energy and smaller customer behaviour change in response to stimuli are of particular importance in achieving energy savings and increasing supply system security. If end use demand profile shape for smaller customers can be changed in response to financial and other stimuli, it can be used to reduce peak generation capacity and spinning reserve and enable demand participation in balancing and reserve markets. With the growth of embedded generation, there are also strong financial motivators for local areas to become "self balancing" in terms of local demand and local generation. Time of Use (TOU) electricity pricing is one mechanism for encouraging energy demand profile shape change. This is already a normal pricing, billing and settlement mechanism for larger customers. It is not generally used for smaller customers where energy use "settlement" costs among suppliers is achieved using "profiles". Single rate and sometimes two rate tariff metering is generally used for smaller customer billing.

The demand elasticity of smaller customer end uses of energy is largely unknown, particularly the financial incentives needed to mobilise specific end use demand changes. It is probable that specific end use profiles can be modified with the right financial incentives. However, the scale of the required incentives, the specific end uses which can be influenced and the size of the resulting demand changes will be different for different households. This report quantifies the potential, value and cost of modifying smaller customer end use demands.

Objectives

Subtask 2 has the objective of quantifying TOU pricing and remote switching as methodologies for motivating and delivering obtrusive as well as unobtrusive changes in specific energy end uses and embedded generation. It also has the objective of evaluating the costs and benefits of implementing tariff, dynamic and real time, TOU pricing systems.

Approach	The approach taken relates together the three main types of TOU pricing; Tariff, Dynamic and Real Time, with particular concentration on whether customers are allowed to manually over ride remote demand switching commands. If no override option is allowed, then single rate tariff metering may be used for billing. Individual end use demand types are considered for their potential to be remotely switched and their possible use inhibited for infrequent, short periods. Notice times required by customers in order to accept remotely switched demand changes as well as reward mechanisms are considered. Quantification of the benefits of Dynamic TOU pricing, in terms of reducing peak demands, and estimation of the costs of implementing individual end use switching is carried out. Results of field trials of TOU pricing carried out in participating countries are presented.
Results	The study has estimated the financial viability of implementing different TOU pricing regimes by equating reliable and flexible demand shift, including operation of embedded generation, with scheduled generation, transmission and distribution network construction costs. In order to do this, the study estimated the costs of implementing Dynamic TOU pricing regimes per kw of demand shift as well as the costs of new supply side construction. Based on comparison of these estimates an annual payment to customers of €234 could be available as an incentive for them to participate in demand shifting regimes. This figure is based on shifting demand for a mix of both electrically and none electrically heated households. If the option to override automatic demand shift signals is not provided for customers, then single rate metering is possible. However, customers are likely to require greater financial incentives to participate in some demand shifting, particularly appliance controls, if an override option is not provided. Other than direct space and water heating demand shift carried out by reducing thermostats, the study has identified air conditioning, lighting and some domestic appliances as potential end uses, which could be moved off-peak. Customer small scale micro generation also has an important role to play in generating outside normal heat led times, and made responsive to TOU pricing. The study identified thermostat reductions of direct space and water heating and air conditioning for a few hours per year are able to make significant contributions to reducing system peak demands. It also identified that small scale micro generation could easily be controlled on the basis of TOU pricing to reduce unscheduled peak demands. Results of Field Trials of dynamic pricing identified that automatic intervention is preferred by customers for shifting demand rather than requiring manual actions. It may also be possible to inhibit demand for short times for each customer but apply it to a large population in sequence to achieve large overall demand reductions for long periods.

Implications	The study identified Tariff, Dynamic and Real Time TOU pricing as delivering valuable demand reductions depending on the end use demands being controlled. The important factors in this regard are that the demand shift is reliable and predictable. The more available the demand shift is, the more valuable it is as an alternative to scheduled generation. Consequently Real Time pricing with automatic demand reduction is the most valuable because it can be used to deal with supply shortages. However, it is likely to be the most expensive to implement. Combinations of Tariff, Dynamic and Real Time pricing can be considered where different demands in the same household are managed by each mechanism. This is particularly the case where no customer override is allowed and single rate metering can be used. Customer acceptance of infrequent and short duration end use inhibits requires evaluation.

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1 INTRODUCTION

Successful implementation of Demand Side participation in competitive markets for energy is essential for world energy sustainability. It is vital that processes presently included and implemented as DSM measures in electricity systems are maintained and developed within liberalised markets. Many liberalised electricity market structures and operating systems mitigate against Demand Side participation, with profile metering for smaller customers an obvious example. Task XI addresses the issues of monitoring and motivating electricity energy end use behaviour changes by smaller customers and mechanisms for their demand side participation via Time of Use Pricing and Demand Side Bidding. It also considers how advanced electricity pricing and monitoring can be used to motivate saving and modify energy use patterns.

End uses of electricity and customer behaviour change in response to stimuli are of particular importance in achieving energy savings and increasing system security. If end use demand profile shape for smaller customers can be changed in response to financial and other stimuli, it can be used to reduce peak generation capacity and spinning reserve and enable demand participation in balancing and reserve markets. Time of use (TOU) pricing and metering is one mechanism for encouraging energy demand profile shape change. This is already the normal pricing, billing and settlement mechanism for larger customers (>100kW demand and other measures). However, it is not generally used for smaller customers where energy “settlement” among suppliers is achieved using “profiles”. Single rate and sometimes two rate metering is used for smaller customer billing. The demand elasticity of smaller customer end uses of energy is largely unknown, particularly the financial incentives needed to mobilise specific end use demand changes. The scale of the required incentives and size of the resulting demand changes will vary greatly for different customers and different households.

Mobilising demand changes and shifting energy use to different time periods has the potential to save energy and money for customers as well as system capacity. The financial savings result from customers taking advantage of lower price energy at non-peak times through tariffs and other more dynamic measures offered by suppliers. Energy and CO_2 saving can result from using the most efficient generating capacity, the extent of the savings being determined by the generation mix in different countries. The motivation for customers to shift energy use is primarily to obtain financial rewards and energy savings. The overall concept of shifting energy use is that the energy will still be used but at different times. Consequently it involves time flexibility by customers as to when they use energy and/or storage of end use energy.

International studies and trials of Dynamic TOU pricing have successfully exposed larger customers to the cost savings achievable by moving electricity demand to lower price periods at reasonably short term notice. It has also been implemented in trials involving small commercial and domestic customers. Studies outlined in Chapter 6 indicate that customers will respond positively to more information about their energy price and be prepared to change consumption behaviour. Trials of TOU pricing showed that customers are prepared to modify their energy consumption to save money and possibly help the environment as long as it involves little effort or inconvenience. Technology developments now allow more detailed information and potential environmental savings to be displayed to smaller consumers, particularly in regard to the impact of TOU pricing and the remote management of end uses of energy.

Exposing smaller customers to time of use energy pricing to influence energy use is only likely to be fully effective and sustainable over the long term if the demand changes in response to price are automatically implemented. Modifying the energy consumption profile assists generators and suppliers to deliver energy at lower cost with part of the savings passed on to customers. Other incentives are the desire by some customers to use "green energy" as much as possible so that they may be persuaded to consume energy when renewable and CHP generation are most likely to be operating rather than rely on quota systems for renewables now in place in some countries. With the rapid growth of embedded generation, there could also be strong financial motivators for local areas to become "self balancing" in terms of local demand and local generation. This could also motivate customers to shift demand to help match demand to renewable generation. However, the extent to which customers would be prepared to do this is not known and would almost certainly involve automatic control of demand.

2 TIME OF USE PRICING AND SMALLER CUSTOMERS

2.1 Time of Use Pricing Definition

Time of use pricing within the context of this IEA, DSM Agreement Task XI Subtask 2 project refers to the presentation of information to customers and end uses of energy regarding the price of electricity based on the time it is consumed. This information can be the actual prices in monetary terms or relative price signals showing high or low prices and times or days of occurrence or possible occurrence. The energy price information can be actual prices in a market or a price related message made up of an energy price and other parameters such as network congestion. The presented prices or signals can also be based on predicted prices for future time periods, such as the next day. They can also be based on a fixed price profile of charges in the form of a previously agreed tariff. The objective of the information presentation is to encourage customers to modify energy use behaviour to avoid high prices and reduce their energy costs. Customer responses to the price signals can be to take manual actions to change demand or allow automatic controls to modify demand.

TOU pricing takes many forms with the main groupings defined as Tariff TOU pricing, Dynamic TOU pricing and Real Time TOU pricing:

Tariff TOU pricing, where times and prices are essentially fixed for long time periods ahead such as months or years. Tariff TOU prices are not able to change when abnormal peak conditions occur. Customers do not have an incentive to reduce more of their load on the highest peak days than on average days, even though load reductions on these days have substantially higher value. An additional problem with Tariff TOU pricing is that if it is implemented on a voluntary basis, only those customers who can lower their bills by going to TOU rates will select it. This leads to a revenue loss that has to be recovered in the form of higher average rates for all customers.

Dynamic TOU pricing is where times and prices can be changed, for example, on a daily basis and provide customers with notice, perhaps 24 hours ahead. Dynamic TOU prices can vary hour by hour but can also be estimated and provided to customers to help them organise demand changes.

Real Time TOU pricing is where customers and their equipment are presented with dynamic prices, near to real time so that demand responses are required to be more or less instantaneous. Variations of Real Time TOU pricing can be where customers are advised perhaps a day ahead that very high price peaks may occur the next day but are not certain. It is also possible to arrange for “capped” Real Time pricing regimes to be applied, where the number of very high price times are pre-defined so as to reduce the risk of large bills by customers. This “capped” arrangement can also be based on a limited number of days or a maximum energy price.

Real Time prices are unpredictable and transfer the bulk of the price risk to customers. It is partly for this reason that they have failed to attract smaller customers.

2.2 Definition of Smaller Customer

Smaller customers are defined within the context of this project as customers who use “profiles” for supplier settlement in competitive markets. Where profile settlement systems are not used, smaller customers are defined as residential and small businesses.

The objective of this study is to quantify the potential and applicability of time of use pricing for smaller customers based on the collective experience of trials, studies and the use of different mechanisms and technologies in participating countries. This assessment will:-

- Quantify what time of use pricing and metering for smaller customers has been implemented in participating countries and results achieved to date.
- Determine the drivers for any achievements made and the potential for applying them in other markets;

- Quantify the requirements for presenting and implementing time of use pricing.
- Quantify technologies needed for time of use pricing
- Estimate cost / benefits of TOU pricing.

2.3 Issues to be addressed

There are many key issues involved in evaluating the potential for using TOU pricing to motivate smaller customer demand changes.

- Can smaller customers be persuaded by time of use pricing to move energy demand or reschedule embedded generation to save money?
- What level of demand changes and energy savings has been achieved in trials?
- What information content and delivery methods provide the greatest demand shift?
- How was TOU pricing and demand shift carried out (Tariff, Dynamic or Real Time)
- How were TOU price signals presented to customers and their end uses of energy
- Can automatic demand response to TOU pricing remove the need for TOU metering?
- How do benefits and costs compare?

2.4 Benefits of Shifting Demand

The benefit of shifting demand by means of TOU pricing or other mechanisms is that shortages in generation or network capacity result in demand reductions. The converse benefit where generation is in surplus and low prices encourage demand can also be valuable. From a market perspective, high prices should result in customers:-

- Not using the planned demand at all.
- Deferring the demand to lower price periods.

<u>Customer Benefits</u>

The benefit to customers of shifting demand is to reduce the cost of energy bills from either or both the above actions. Customers also receive increased supply security due to the additional flexibility provided to System Operators. System operation costs may also be reduced because of reduced scheduled generation standby capacity.

<u>Society Benefits</u>

The benefits to society resulting from a reliable and flexible demand side response is the probable reduced CO_2 emissions and increased supply security due to System Operators being able to use the demand side instead of scheduling generation.

System Operator Benefits

System Operators can provide increased supply security at lower cost if demand elasticity is able to be activated flexibly in response to price signals and is sufficiently reliable to be included in generation planning and scheduling.

From a System Operator perspective, the critical issues are:-

- Is the demand available for reduction at the right time and place?
- Will the demand reduce when the price increases?
- Will the demand return when the price reduces?
- Is the reliability and predictability of the process acceptably high?

Any constraints on how often or when the demand side measures can be permitted to operate as a result of customer dissatisfaction or customers overriding the automatic systems will reduce the value to System Operators. Identifying customer imposed constraints on demand disruption is discussed in Chapter 4.

3 POTENTIAL FOR SMALLER CUSTOMER DEMAND SHIFT

In principle, all demand can be made to respond to prices if the price messages are sufficiently strong.

Examples of actions which customers can take or which are taken for them by automatic systems by prior agreement are:-

- Turn off/down lighting
- Turn off/down heat thermostats
- Don't use kettles, etc
- Turn off/up air conditioning thermostats
- Clothes and dishwashing periods moved (end use inhibit)
- Cooking period moved/ modify cooking appliance use
- Modify embedded generation schedule
- Turn off/down water heating thermostat
- Turn off refrigeration for short period
- Turn off/inhibit sauna, direct showers (end use inhibit)

However, in reality, price messages can only be as strong as made possible by the cost savings which are delivered by shifting elements of demand. In order to quantify the potential for system demand reduction by smaller customers, it is necessary to understand the role of smaller customers in creating system peak demands. Disaggregated, system peak demand curves for Finland and Spain are shown in Figs 1 and 2.

Fig 1
FINLAND

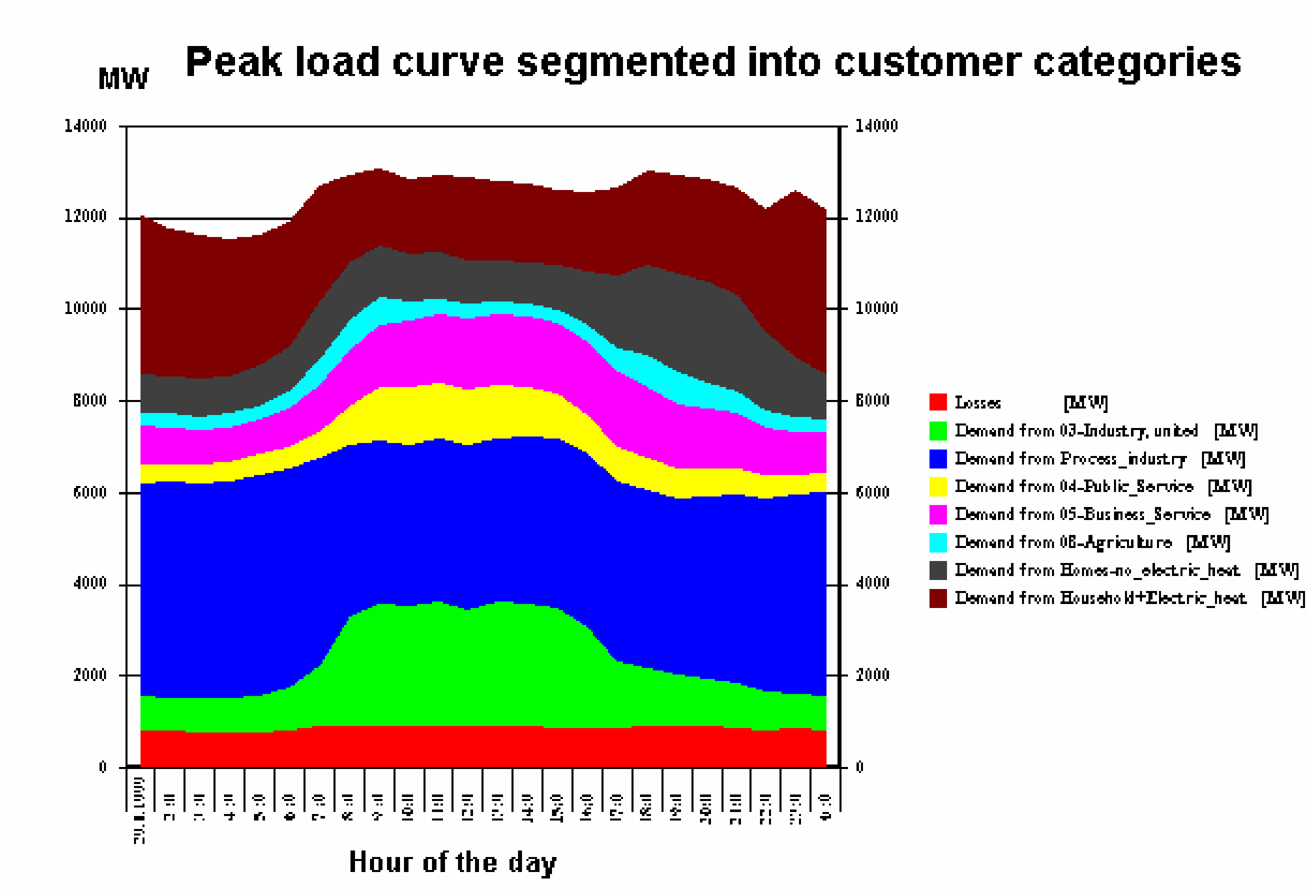
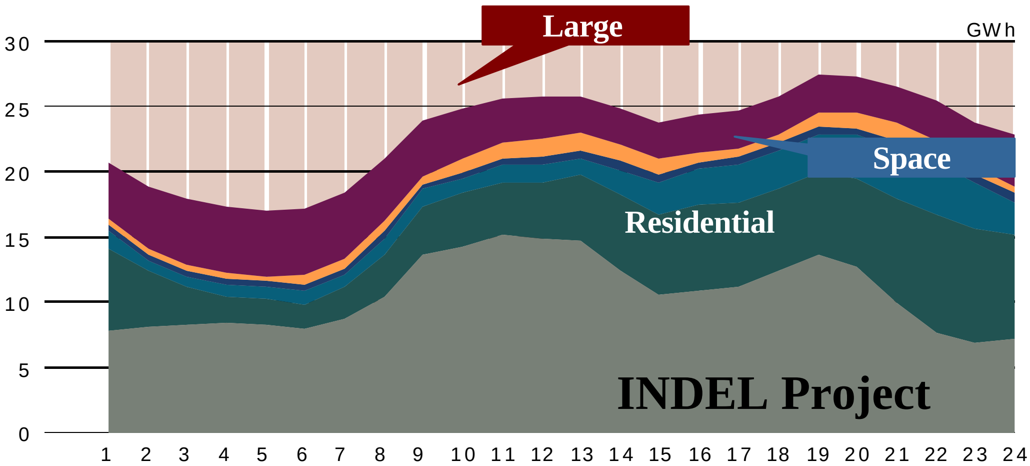


Fig 2
SPAIN
Peak Load Curve for Smaller Customers

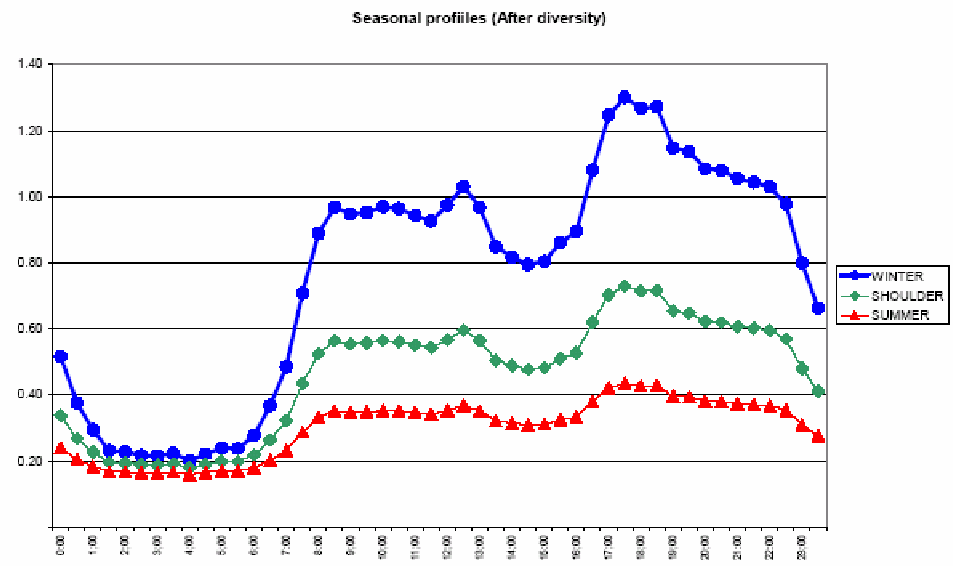


These show that in Finland, 2 million, none electrically heated households contribute a maximum of 1,100MW to system peak demand in the morning, resulting in an average peak demand per customer of 550W. 580,000 electrically heated households (direct and storage heating) contribute a maximum of 1700MW to system peak demand in the morning, resulting in an average peak demand per customer of 2.9kW. The corresponding average peak demand per customer in the evening is 1kW for none electrically heated households, and 3.5kW for electrically heated households.

In Spain, smaller customer demand represents between 7000 and 14000 MW of the peak day demand load curve. This represents between 25% and 50% of peak demand. Electric space heating demand represents only 20% of the total smaller customer peak demand, with a large demand resulting from air conditioning. However, the electric heating demand results from relatively few customers with the total population of smaller customers delivering the other 80% of smaller customer peak demand. In Spain there are approximately 21 million smaller customers contributing a maximum peak demand of 14000 MW. This results in an average peak demand of 670 watts per customer. The average consumption per customer is 4,000 kWh/year resulting in an average bill of 400 Euro/year. The 21 million residential customers contribute 31% of total electricity consumption. Small businesses comprise 500,000 customers and contribute 16% of total consumption with an average bill of 4.800 Euro/year.

Consequently in Spain, there is a stronger case than in Finland for considering all smaller customers for TOU pricing rather than just electric heating customers.

The size of the average smaller customer demand, excluding space and hot water heating which occurs on peak for a large population can also be estimated from the After Diversity Maximum Demand, (ADMD) figures used in network design. In the UK, an ADMD of 1 to 1.5 kW per customer is used as a design parameter for LV network design for housing estates without electric heating. The shape of this average load curve is shown in Fig 3. The value is higher in Finland and Netherlands where saunas are common. However, the value of 1 to 1.5 kW per customer provides another useful estimate of the average peak demand per smaller customer which, in principle, could be moved as a result of a large population responding to TOU prices.



Source: System Integration of Additional Micro-Generation (SIAM) DTI Distribution Generation Program report DG/CG/00028/00/00 URN NUMBER 04/1664

Figure 3 After Diversity Demand of a Typical UK Household

3.1 What is smaller customer demand shift worth?

If smaller customer demand changes carried out in response to price messages can be made sufficiently reliable and predictable to displace scheduled generation then it can be considered to be of equal value. The removal of generation also removes the need for new transmission and distribution construction. The combined capital value of these items is many hundreds of Euros per kW. Figures between 700 to 1500 Euros per kW, with an average of 1000 Euro per kW for different types of generation, transmission and distribution construction have been used to estimate ballpark benefits of TOU pricing.

In the UK, for information, onshore and offshore wind generation cost on average 900 Euro per kW and 1400 Euro per kW respectively.

New gas fired CCGT plant has a capital cost of the order of 580 Euro/kW.

4 TOU PRICING TO DELIVER SMALLER CUSTOMER DEMAND RESPONSE

Understanding the potential for different elements of smaller customer demand to respond to different pricing mechanisms is key to evaluating the role of TOU pricing as a reliable Demand Response motivating measure.

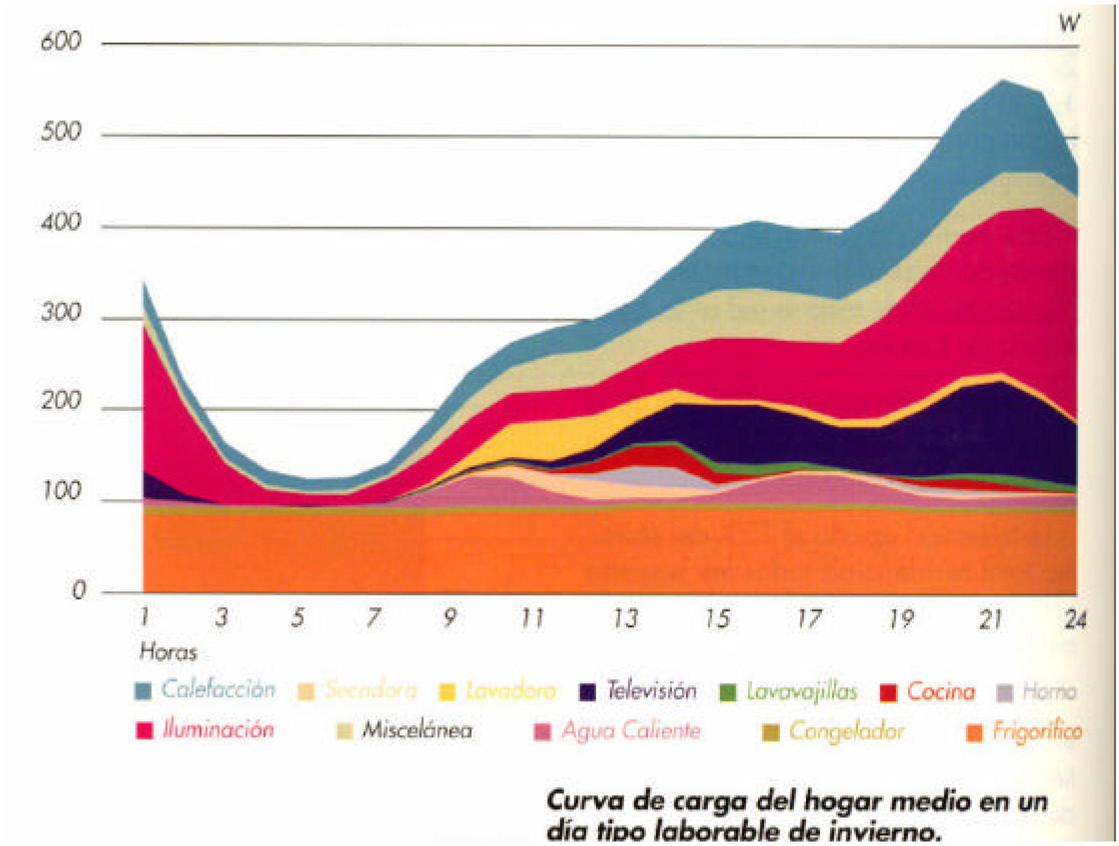
The financial rewards which can be made available and used to encourage customers to shift demand can be estimated from consideration of the value of demand flexibility to supply side operations. This value provides the resources from which customers can be motivated for beneficial demand side profile changes. Demand management in this context includes the operation of small scale micro generation at customer premises in response to price. If the demand side can be made as flexible and reliable in operation and delivery as supply side dispatched generation then their values could be considered similar as discussed in Chapter 1. This enables 1kW of demand side to be equated with 1kW of supply side including central generation, transmission and distribution networks. However, the demand side generally is not as flexible and may not be as reliable as the supply side so that the value of different levels and characteristics of demand side responses need to be considered against the supply side reference.

Time of use pricing has many forms of implementation focussing mainly on the different notice times of price changes and whether the demand shift actions are automatic or optional by customers. Time of use pricing based on tariffs usually comprises fixed times and prices against which demand can be taken and charged. Time of use pricing based on dynamic price messages delivers prices and times which can change continuously. However, some notice time of projected prices is provided to customers to assist them in planning demand side energy use. Usually a notice time of 24 hours is considered appropriate. Time of use pricing based on Real Time, hour by hour pricing and charging, delivers energy prices in near to real time. Consequently there is nominally no notice period of absolute prices to enable the demand side to schedule energy use. Real Time Pricing regimes sometimes include warnings to customers informing them that high prices may occur during the next day or other period. It is possible to have automatic contingency plans in place in anticipation of high prices which switch elements of demand automatically.

4.1 Smaller Customer Peak Demand Aggregation

Understanding the components of smaller customer contributions to system peak demand is critical to identifying the end use demand to target with TOU pricing. Fig 4 shows the average smaller customer contribution (570 watts) to system peak demand in Spain.

Fig 4
Smaller Customer Individual End Use Contribution to Peak Demand in Spain



This curve shows demand contributions from :-

Spanish	English
Calefaccion	Space Heating
Lavavajillas	Clothes Washing Machine
Secadora	Tumble Dryer
Television	Television
Lavadora	Dishwasher
Cocina	Cooker
Horna	Oven
Illuminacion	Lighting
Miscelanea	Miscellaneous
Agua Caliente	Water Heating
Congelador	Freezer
Frigorifico	Refrigerator

From the figure, direct space heating is shown to be an important contributor to system peak. Lighting is also shown to be a large contributor with TV and fridges also important. Dishwashers, clothes washers and freezers are shown to be of relatively minor importance but nevertheless are identifiable contributors.

Fig 5

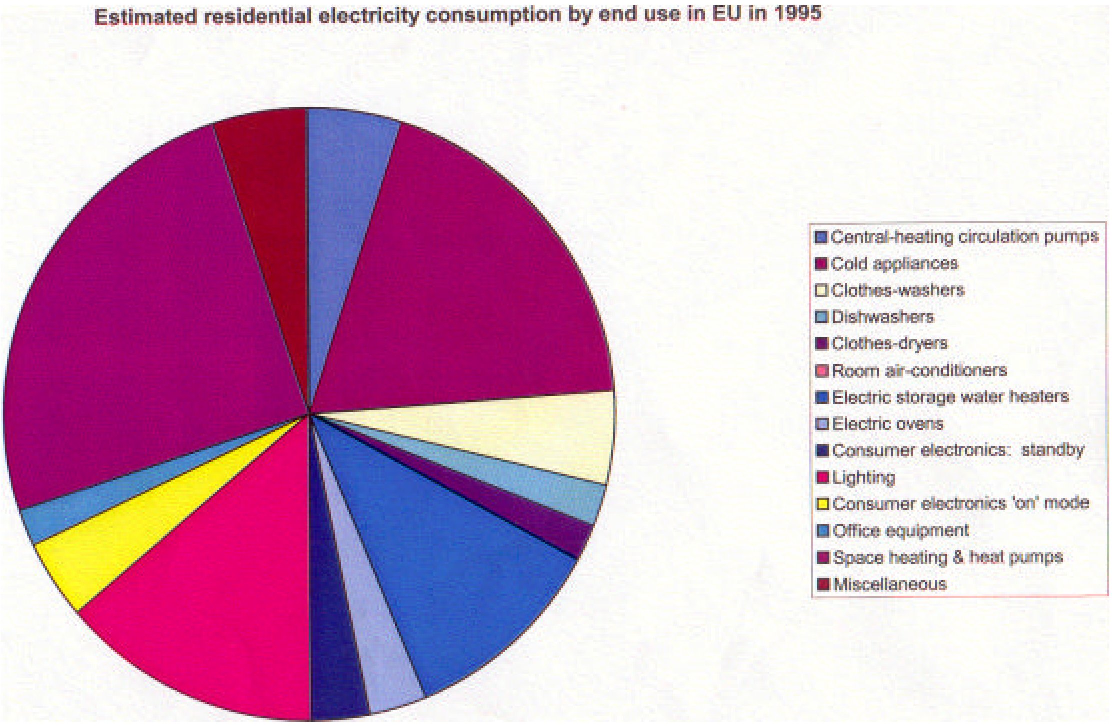
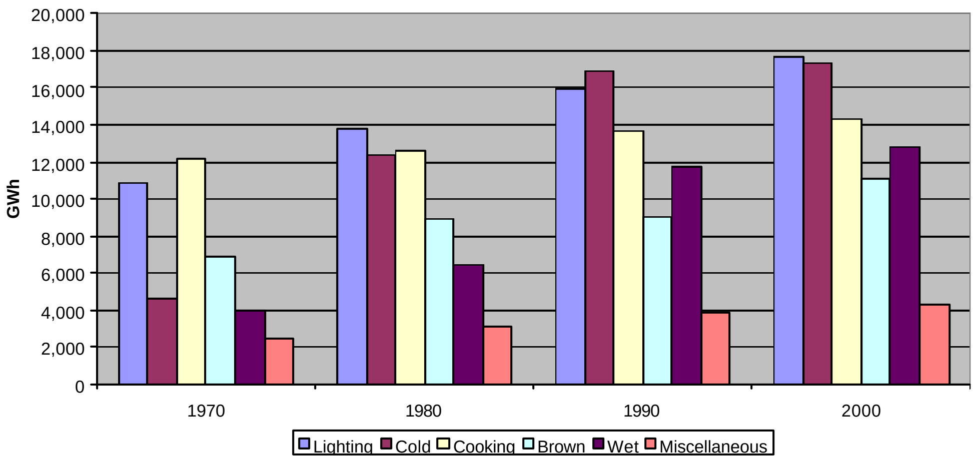


Fig 6 Electricity consumption by household appliances



Source: Energy Consumption in the UK, Department of Trade and Industry

For the EU in 1995, Fig. 5 shows a breakdown of major electricity energy uses for smaller customers. Fig 6 shows electricity consumption data for the UK between 1970 and 2000. This shows major contributions from space heating in the EU and lighting in both figures. However, this energy use data is only indicative and cannot be used in estimating peak demand.

4.2 Potential Demand Available for TOU Pricing

In order to estimate the potential for TOU pricing to influence specific demand changes, consideration of individual end uses of electricity and the systems and technologies needed to change their use and customer behaviour is required.

This is a wide ranging issue because customers vary greatly regarding the incentives required in order for them to tolerate even minor inconvenience resulting from electricity reduction or non availability of end use applications.

Customers also vary in the composition of demand, based on country climate and national behaviour patterns. From Chapter 1, the average contribution made to peak demand by each smaller customer varied between 670 Watts for Spain to 2KW (electrically and none electrically heated customers) for Finland with the UK in between. However, some of the end uses which contribute to peak demand are likely to be similar in all countries. This is particularly the case for space and water heating although these will have larger kW and kWh values for the colder climates. Air conditioning for smaller customers is likely to be a larger system peak contributor in warmer climates. Lighting will be a common end use in all countries but the shorter daylight hours available in northern countries will make the kWh demand greater.

4.3 Customer Groups

In order to estimate the potential for demand shifting as a result of TOU price messages and controls, smaller customers have been classified into four groups based on their major energy end uses. Customers with:

- Electric storage, space and water heating + appliances + air conditioning
- Direct electric space and water heating + appliances + air conditioning
- No electric space or water heating + appliances + air conditioning
- µCHP/ fuel cell space and water heating + appliances + air conditioning

The four groups of customers are considered as potential respondents to TOU pricing using:

- Tariff TOU Pricing
- Dynamic TOU Pricing
- Real Time TOU Pricing

4.4 Tariff TOU Pricing

TOU pricing using tariffs has been implemented in participating countries for many years. The basis of the pricing is organised around multi rate, time of day and sometimes seasonal tariffs. These tariffs have fixed energy prices for the fixed times and seasons. However, the prices can be easily changed. Multi rate metering is used to accumulate energy consumed at the different times. Different regimes are used in different applications of TOU tariffs.

Some arrangements allow only storage, space and water heating energy to be accumulated on the low price meter register. Other arrangements allow any or all of the household demand to be accumulated on the low rate register based on a combination of automatic and manual switching. Switching of the meter register between high and low rates is carried out by pre programmed, spring reserve time switches or by remote communication signals. When the register is switched from high to low rate, the heating and water heating are also switched automatically. On systems which allow the other household demand to be consumed at the low rate, this is switched manually. Consequently the demand in these situations is separated into automatic low rate and low rate based on customers choosing the option on a day by day basis.

4.4.1 Tariff TOU Systems

In Finland, the total number of electrically heated houses is about 600,000. Domestic hot water is usually produced during the night-time and houses have 300 litres of hot water storage which is normally large enough to avoid daytime heating of hot water. Hot water switching is automatic based either on time switches in TOU meters or on remote switching using ripple control or Distribution Line Carrier (DLC). Customers have the option to manually switch on the heating during the day-time if there is a requirement for additional hot water.

Many customers also have special contracts with suppliers which allow direct control of part of the direct electric space heating for short periods (1–2 hours) during peak demand periods. This was applied within the structure of old whole sale tariffs which included very high demand charges for wholesalers. Ripple control and DLC were used for that control. Following the introduction of the electricity market, the motivation has disappeared, but the technology still exists and is used for tariff and hot water storage switching.

In many cases the electrification of houses is arranged in such a way that when saunas are switched on (load about 10 kW) part of the heating is switched off. Thus the connection fuse size can be minimised usually to 3 x 25 A on a 3 phase supply. This reduces the cost to customers, because the fixed charge depends on fuse size.

In older electrically heated houses radiators with individual thermostats are used. In some cases separate ceramic heat storage units have been used. In newer houses if radiators are used, they are usually centrally controlled and have the option to programme automatic changes to room temperatures with different types of alternative schedules.

At the present time, the usual arrangement for new houses is that there are no separate radiators; heating is based on floor heating with heat cables laid inside 8–10 cm of concrete on the ground floor which provides heat storage. Floor heating can be combined with ceiling heating as well as electrically heated windows. These systems usually have an automation system for the control of heating.

In addition to hot water and space heating, dishwashing and clothes washing machines, as well as saunas, are often used in low price periods depending on the time zones offered by the supplier. These are manually controlled and optional by customers.

For new potential TOU Price customers, there are internet-based calculator models available where they can compare prices with different types of TOU tariffs. These are based on general load profiles and annual consumption. However, they do not include details of the extra costs related to metering etc. The inclusion of this kind of information is considered too complicated. Customers are already claiming that bills which include separate information on network prices, supply prices, electricity taxes and VAT are too complicated. The bill also includes a comparison of the consumption between consecutive years and also a description of the supply fuel mix.

In summary therefore, customers have the option to influence demand use against energy price by operating switches manually or agreeing to remotely switched demand. As far as storage demand is concerned, switching to store energy at low price times is relatively unobtrusive to customers. The appliance demand, which is optional as to whether it is used or not in high price periods, is in general not secure or reliable as a demand side measure as far as the System Operator is concerned. With large populations of customers using TOU tariffs for optional loads, some appliance demand shift could be considered reasonably reliable. The ratio of price message rates between peak and off peak is usually a factor of approximately two with the off peak rate being half the on peak rate. The number of time zones (registers in the meter) is usually 2–4.

Seasonal tariffs have the highest rate during working days, but only usually between 1st November and the end of March. During the summer season there may also be two rates.

Typical TOU prices in Finland

	Electricity	Network	El- tax	Total
Fixed charge €/month	2,40	4,54		6,94
Day time in working days c/kW h	4,79	3,42	0,91	9,12
All other times c/KW h	3,20	1,89	0,91	6,00

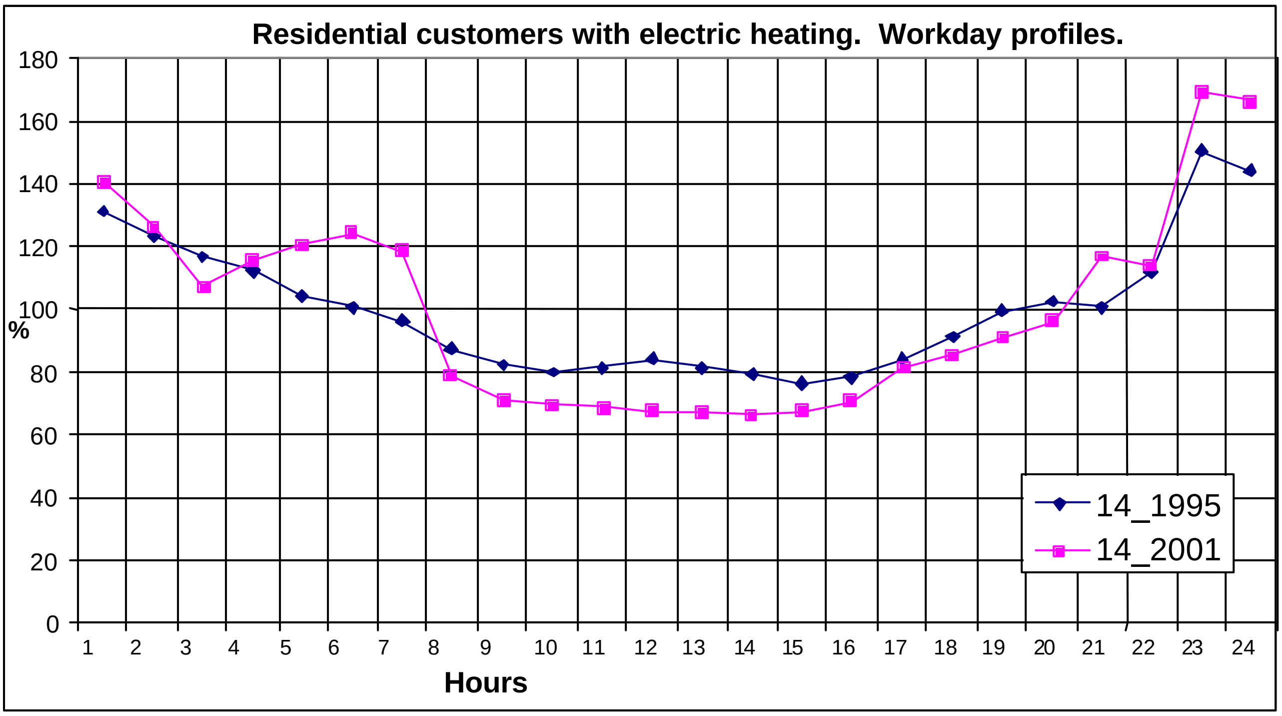
For most appliances responding to TOU rates, the financial savings will be small. Applications such as saunas, car heaters, direct on showers and direct space heating and cooling have the potential to deliver significant savings. These energy use applications could be made to respond automatically to price changes in order to improve the reliability of demand shift away from high price times and increase their value to the System Operator.

It is economical for customers in Finland with annual consumptions above 12-15000kWh to choose TOU tariffs. This means that in practice almost all electrically heated houses use TOU tariffs as well as agricultural, industrial and service sector customers.

As a result of the above measures, the average load profile of electrically heated houses in Finland has been changed to a level where the day-time consumption is low compared to that in Denmark and Norway where domestic hot water is produced in daytime and buildings usually have normal radiators without storage capabilities. The average load curve for electric heating in

Finland is shown in Fig 7 (year 1995 and 2001).

Fig 7



In Spain, 4.5% of domestic customers use a day/night tariff which accounts for 14% of electricity consumption in this category. The day/night tariff for smaller customers allows the option of all of the demand to be taken by manually switching individual end uses of energy. Only the final cost of the consumed energy is important to customers as a motivator to persuade them to reduce or shift demand. Strong marketing and promotion has been carried out to create a TOU pricing and energy and money saving environment.

In Netherlands most utilities install, two rate meters as standard, with the majority now electronic. New electronic meters contain between 2 and 5 tariff registers. Electricity use in typical Dutch households is relatively low. Only about 50% of the annual total energy consumption is electricity, the other 50% is natural gas which is used for space heating.

As a service to customers, utilities calculate the yearly final bill using the most attractive tariff; single tariff or two rate tariff (depending on the minimum consumption and kWh price levels). This means that customers can be sure that they are paying the lowest energy prices. The Dutch Ministry of Economic Affairs is carrying out a study of Demand Response metering opportunities, including TOU pricing, for smaller customers. The most important driver for this study is the expectation that within five years there will be capacity shortages in generation and networks.

In Netherlands, the most important motivator to encourage customers to modify their demand is energy cost savings. Household customers with electric boilers (3 kW) use TOU pricing and are switched automatically by their supplier which reduces the contribution to system peak demand by an average of 1 kW per customer.

Households have the option to use demand at any time and there is no maximum demand charge or limitation on their consumption. The kWh price for smaller customer TOU pricing is Euro 0,053 (Low rate) and Euro 0,095 (High rate). These are energy prices without additional taxes, standing charges, etc.

In Denmark before market liberalisation, TOU tariffs were offered to all smaller customers, normally in the form of a simple three-rate tariff. The three-rate tariff was considered advantageous for smaller users with direct electric heating. The difference between the high and low rates is relatively small. This small difference is because of the Nord Pool market, which has a significant hydro component. A yearly consumption in excess of 10.000 kWh is usually required in order for the TOU tariff to be viable. No survey of the effect on the consumption pattern as a result of TOU prices is available.

At the present time in Denmark, TOU pricing is only offered to large customers, with very few smaller customers still using TOU tariffs. A successful campaign in Denmark to convert direct electric heating for smaller customers to other heating means such as gas has reduced the number of customers with high electricity demand.

There are some 25 million domestic customers in the UK. Of these approximately 8% (2 million) have electric storage heating. The remainder generally use gas for space and water heating. All of the electric space and water heating customers have two rate metering – with a low off peak night rate (price per kWh) and a higher day rate, Table 1. Generally the heating, wiring circuits are separate from the other circuits in UK households and are the only ones metered and switched for off-peak use.

Table 1 Residential Time of Use Tariffs[1]

	Standing Charge	Day Units			Night Units
		First tier	For units up to	Remaining day units	
	p/day	p/kWh	kWh	p/kWh	kWh
Scottish Power	17.8	7.72	all		2.29

[1] Correct as of 12 May 2004

Scottish and Southern	19.16	6.74	all		2.43
Powergen	15.48	7.308	all		3.20
Npower		18.17	728 kWh/yr	7.30	2.86
EDF Energy		14.43	250 kWh/yr	7.97	3.08
British Gas		14.33	250 kWh/yr	6.49	2.78

Standard storage heater controls allow charging (at off-peak rates) over a 7 or 8 hour period set by a time clock or remotely switched contactor for the heating circuits. The only control of charge is by the householder varying the settings of the individual heaters – thus turning demand down during periods of warm weather.

A broadcast radio based system (Teleswitch) using one of the national radio broadcast frequencies (200kHz) is currently used in the UK for limited, dynamic load shifting of domestic storage heating. This is operated by the transmission System Operator under instruction of Suppliers.

There are, however, a number of other systems which provide more sophisticated control that automatically limits charging during warm weather. Some of these provide the means of flexible charging regimes according to price signals.

4.4.2 Additional End Use Demand Change Potential using Tariff TOU Pricing

Many end use demands have already been moved off peak as a result of using existing TOU Tariff systems. Consideration is now given to what additional end use demand may be motivated to move off peak as a result of applying new TOU tariff systems. In order to do this, the four customer groups and their demands are considered for more extensive TOU tariff pricing implementation.

CUSTOMERS WITH ELECTRIC STORAGE, SPACE CONDITIONING AND WATER HEATING AND APPLIANCES

These customers already have the storage, space and water heating demand taken in low price, periods so that the only demand which could be motivated to move off peak by TOU tariffs is the 1 kW to 2 kW of appliance demand, lighting and the air conditioning. However, because the peak and valley prices are predefined and built into the tariff there is no flexibility to change customer behaviour in response to system peaks occurring at other times. The predictability of the lighting and appliance demand being moved off peak as manually implemented customer actions in response to price is also very much open to question and would be considered unreliable by system operators. The use of automatic inhibits applied to some appliances based on customer agreement for a limited number of times or hours per year could have potential. Automatic reduction in lighting levels could also be considered in the same way. Centrally controlled, air conditioning demand is an attractive option for shifting off-peak by changing temperature set points.

CUSTOMERS WITH DIRECT ELECTRIC SPACE CONDITIONING AND WATER HEATING AND APPLIANCES

These customers have more potential to move demand from peak times than customers with storage demand because part of the demand is presently taken on peak. With these customers, it would be possible to motivate a shift of several kW from peak demand by means of TOU price incentives. Measures such as automatic reduction in thermostat settings for heating and cooling in response to price changes can move the demand. However, the inflexibility of TOU tariff switching means that the potential to reduce the demand at other than the pre-planned times cannot be used. Lighting reduction and appliance inhibits could also be used to move demand for very critical peaks.

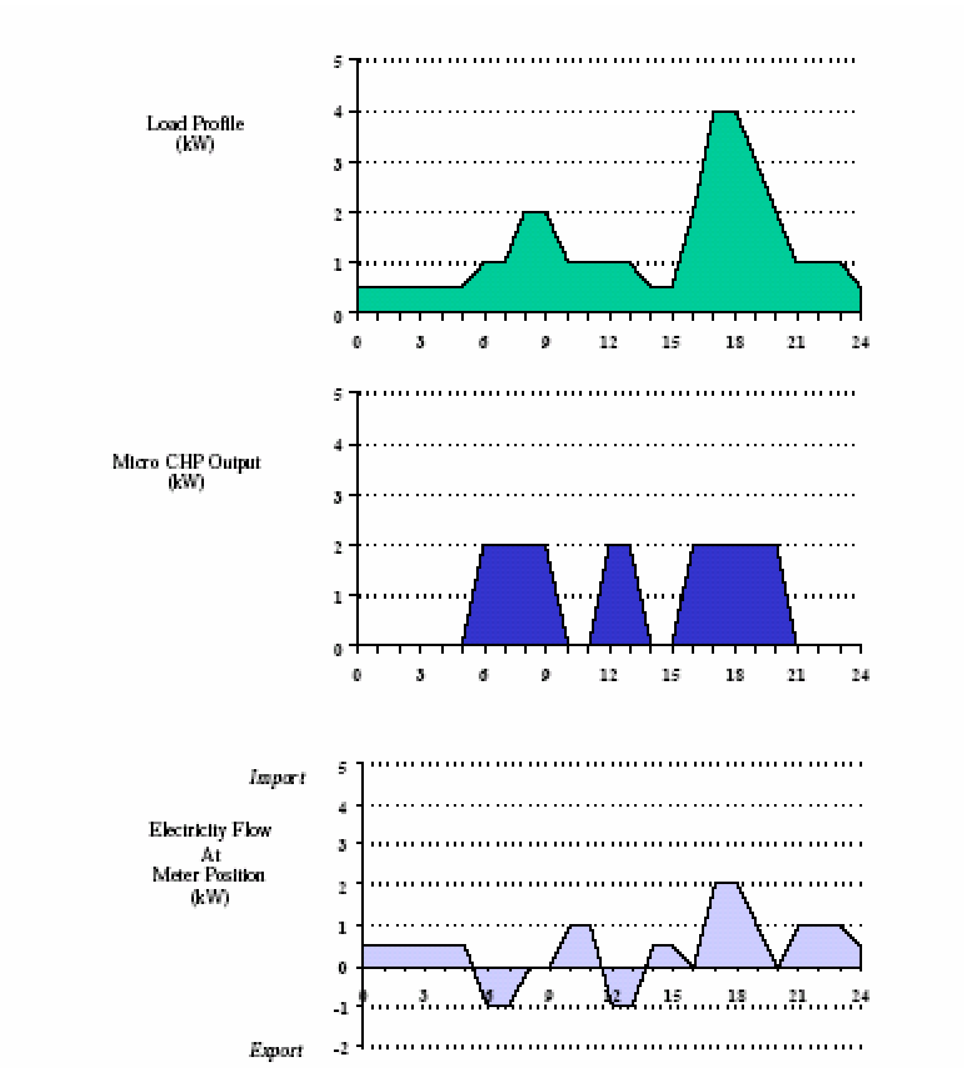
CUSTOMERS WITH NO ELECTRIC SPACE AND WATER HEATING + APPLIANCES AND AIR CONDITIONING

These customers have essentially the same potential to move electricity demand off peak in response to TOU prices as those with storage demand which is already off peak. They would have gas or other fuel to provide space and water heating so that the appliance, lighting and air conditioning demand of 1 to 1.5 kW would be available to move off-peak

CUSTOMERS WITH µCHP/FUEL CELL SPACE AND WATER HEATING + APPLIANCES

These customers use gas or other fuel to deliver space and water heating. They also produce electricity from the CHP or fuel cell plants. However, the electrical output for smaller customer generator systems is of the order 1-3kW. Consequently peak electrical demand of the household will be met by input from the grid, Fig 8.

Fig 8
Typical import/export profile for MICRO generator customer



Small customer generator systems are heat led so that they would be generating at normal system peak demand times as a matter of routine. If heat storage systems are included in the installations, then generators could be motivated to generate at other times by the offer of price incentives. With tariff pricing for these customers, the 1 to 2kW of appliance, lighting and air conditioning demand could be moved off peak.

4.4.3 Summary of Tariff TOU Pricing

For many customers, there is the potential to move demand from peak times in response to TOU tariff pricing. This demand is greatest for direct electric space, water heating and air conditioning customers where modifying thermostat set points at times of peak demand would reduce average demand. All customers have the potential to move some appliance and lighting demand from peak to off peak times (1-2kW), possibly by using a tariff which includes a higher price for a few times per year, together with an automatic switching regime. However, the inflexibility of TOU tariff price signals means that demand peaks other than those pre-set in the tariff cannot be dealt with and in some ways are exacerbated by TOU tariffs. Consequently TOU tariffs and the demand reduction they may generate cannot be considered equivalent to scheduled generation. Therefore the only incentives which can be offered as motivation for customers to adopt TOU tariffs to move demand is the energy price differential which is a factor of 2 or less between peak and off peak prices.

4.5 Dynamic TOU Pricing (24 hours ahead)

Dynamic Pricing uses estimated real time pricing for the next time period, possibly 24 hours ahead. This pricing regime allows System Operators or suppliers to consider all the issues influencing price for the period ahead and structure prices messages with which to motivate changes in customer demand profiles. Dynamic pricing motivates demand shift away from high price times in a similar way to TOU tariff signals. However, because Dynamic Pricing allows near real time changes in price profile to be used, the response is more attractive to system operators in dealing with abnormal system demand problems. In particular it allows predicted demand peaks which occur at unusual times to be built into the price messages and so influence customer demand. If demand response to price messages is automatic, then the value of the process in terms of reliability and flexibility of delivery, approaches that of a generator in meeting peaks at unscheduled times.

From a customer perspective, Dynamic Pricing introduces a more complex regime in terms of them modifying optional demand because it requires them to be attentive to energy price on a continuous basis.

With dynamic pricing based on spot prices the price for the next day is known the day before in the afternoon. It is available on the Internet in some countries and customers can get information via mobile or e-mail if the price level exceeds a predefined value during some hours of the next day.

Many studies have been carried out in participating countries to quantify the impact and potential value of dynamic pricing for smaller customers. These range from providing price indicators to motivate manual response, to fully integrated control of storage and direct heating systems. Other studies have allowed the specification of customer preferences when the use of certain demand can be inhibited.

Again an assessment of the motivating influences on the demand of the four categories of smaller customer has been carried out in order to understand the potential value of Dynamic TOU pricing.

CUSTOMERS WITH ELECTRIC STORAGE SPACE CONDITIONING AND WATER HEATING + APPLIANCES

Dynamic tariffs can be applied to all the demand of these customers and allows more flexibility than TOU tariffs in the scheduling of storage demand.

In particular it is possible to automatically schedule storage space and water heating so as to deal with abnormal generation or network peaks. This can be carried out by direct modification of the price messages. The appliance, lighting and air conditioning demand can also be motivated to move from peak times by the 24 hour ahead price signals allowing customers the opportunity to reschedule their use and accept reduced air conditioning set points and possibly lighting intensity. However, although the storage demand would be predictable and reliable in response to the dynamic pricing, the appliance, lighting and air conditioning demand would be unreliable unless some form of automatic inhibit was able to be applied at high cost times without customers having override possibilities.

If TOU metering was included so as to allow override of the automatic switching, it would provide a disincentive for customers to actually override it.

<u>DIRECT ELECTRIC SPACE CONDITIONING AND WATER HEATING + APPLIANCES</u>

Dynamic pricing can be a significant motivator for this customer demand although it requires customers to be vigilant regarding the price signals. It is likely that for long term sustainability of customer and demand behaviour change in response to price messages that automatic systems are used. These systems would automatically modify thermostat and lighting settings and possibly inhibit appliances, for short and infrequent periods, based on customer prior approval of the number of times of occurrence and duration.

<u>NON ELECTRIC SPACE OR WATER HEATING + APPLIANCES + AIR CONDITIONING</u>

These customers have only the appliance, lighting and air conditioning demand of 1-2 kW to be influenced by price signals. A demand change in response to dynamic pricing based on customers taking manual action would be unreliable and therefore of limited value to System Operators. If automated responses to the dynamic prices were included with no customer override, then the value of this pricing mechanism would be much greater. Single rate metering may also be possible.

<u>µCHP/FUEL CELL SPACE AND WATERHEATING + APPLIANCES</u>

These customers could be motivated to deliver more than demand shifting in response to dynamic pricing if the local generator was also electricity price responsive. This would require heat storage to enable the generator to operate at high price times when heat was not required. With automatic processes in place, the reliability of this generation would be high and valuable in system operation.

4.5.1 Summary of Dynamic TOU Prices

Dynamic pricing as a demand shift motivator is more powerful and flexible than TOU tariff based systems because it can motivate demand changes in response to short notice system or network peak requirements. The demand changes it can motivate especially with automatic processes make it a reliable contributor to system peak reductions whenever they occur.

For direct electric space and water heating, air conditioning, lighting and appliances, customer motivation to reduce peak demand by a few kW per customer could be provided reliably by dynamic prices. Using dynamic prices to motivate local generation to operate and contribute to peak demands outside normal operating times would also have value to System Operators if it was an automatic and reliable process.

If the implementation of demand changes is carried out automatically within pre agreed constraints, it is possible to consider single rate metering as being acceptable, providing no override of the automatic switching is allowed.

4.6 Real Time TOU Pricing

Real time pricing is difficult for smaller customers to respond to manually and requires automatic operation of small scale generation systems, direct space and water heating and air conditioning set points and lighting reduction in order to be effective. Smaller customers require the ability to plan lifestyle so that appliance demand inhibit is unlikely to be accepted as a result of real time pricing signals. Again, however, if the number of inhibits actually applied to appliances was small and some advance notice of possible high prices was included, then customers may agree to the disruption of lifestyle. Override of the inhibits could be allowed but this reduces the reliability of demand change and hence its value. It also requires TOU metering.

The four customer groups are now considered for Real Time TOU pricing.

<u>STORAGE ELECTRIC SPACE AND WATER HEATING + APPLIANCES + AIR CONDITIONING</u>

These customers are unlikely to have demand which can be motivated to shift based on real time pricing. Storage, space and water heating require defined energy for charging the heat store so that forward planning of charge and discharge schedules is needed. There is a possibility that refrigeration appliances could be interrupted for short periods in response to instantaneous price but this would require an automated restoration after a defined time period irrespective of price. Consequently the benefits would be minimal. Air conditioning set points could be changed for short periods, especially if the total number of changes per year was pre-defined and agreed. The same is also possible for appliances and lighting.

<u>DIRECT ELECTRIC SPACE CONDITIONING AND WATER HEATING + APPLIANCES + AIR CONDITIONING</u>

The same response to motivating appliance energy use schedules by means of real time TOU pricing applies here as to the previous customer types. However, the direct space and water heating and air conditioning energy use could respond automatically by changing thermostat settings in response to instantaneous price. This would allow the demand of a few kW to be moved to deal with abnormal peak demand or congestion situations. This demand change would be predictable and reliable if no override was allowed and so would have high value in replacing scheduled generation. Appliance and lighting inhibits and reductions could also be included.

NO ELECTRIC SPACE OR WATER HEATING + AIR CONDITIONING + APPLIANCES

The only demands which potentially can be motivated to change in response to real time pricing are those of the air conditioning units, appliances and lighting. These could respond automatically to real price signals and modify thermostat settings, disable appliance use and reduce lighting level. This process could deliver average reductions in demand of 1-2 kW depending on the change in settings, etc. An automatic demand reduction of air conditioning would be reliable and predictable in the summer months and as such would be valuable in replacing scheduled generation. It is believed that in general, customers would not override automatic temperature settings if the option was provided, especially if TOU metering was used.

µCHP/FUEL CELL SPACE AND WATER HEATING + AIR CONDITIONING + APPLIANCES

Appliances, lighting, air conditioning and possibly refrigeration plant could effectively respond to instantaneous price change signals. Reducing automatically the air conditioning thermostat, disabling appliances and reducing lighting levels would deliver perhaps 1-2 kW average demand reduction. The space and water heating generator would be able to generate outside normal operation periods and store heat. This would allow the generated electricity to assist with unscheduled system peaks or congestion. Because the process is fully automatic, it is predictable and reliable and therefore valuable to System Operators as an alternative to scheduled generation.

4.6.1 Summary of Real Time TOU Pricing

Real time pricing is very flexible in sending the right price messages to demand and as such, any reliable response is valuable to System Operators. Direct space and water heating and air conditioning demand could easily respond automatically to real time pricing signals. This can deliver more than 2 kW of average demand reduction as a result of modified thermostat settings. Switching of direct heating and cooling in selected rooms makes it more acceptable to customers. Micro generation could be arranged to respond to real time prices and generate outside the normal heat led times and contribute 1kW of generation to assist with meeting unscheduled peaks.

The issue of providing customers with override options to the automatic demand switching process needs careful consideration. Single rate metering may be possible if no override option is allowed. Customer perception of the consequences of having no override option is critical to the acceptance or otherwise of remote and automatic switching of demand, particularly for appliance inhibits and possibly lighting. Providing the number of times per year the demand is switched with no override option is kept small, it may well be accepted by customers. This acceptance process will require the financial and environmental benefits to be well marketed.

4.7 Summary of TOU Pricing

The previous sections have estimated the possible demand responses which could take place if motivated by different methods of TOU pricing. From a System Operator perspective, real time pricing and automatic, demand changes need to compare favourably with scheduled generation in order to be of equivalent value. Dynamic prices and automatic responses approximate the performance of a scheduled generator except that 24 hours notice is required. This makes it less able to respond to short term incidents. Fixed time of use tariff based prices and times have no flexibility as far as the system operator is concerned, although the automatically switched fixed space heating and water heating demand moved off peak is a valuable contribution to reducing scheduled peak capacity requirements. Where customers also have manual or automatic options to use other demand at off-peak times, this generates a small amount of peak demand reduction. However, any optional demand shift carried out by customers from high price to low price times and switched manually is unpredictable and unreliable and cannot be regarded as reliably replacing scheduled generation. Some flexibility can be introduced if remote time switching is used rather than time clocks to switch meter register and demand. This enables peak demands occurring in nominally off peak times to be reduced.

Dynamic pricing and Real Time pricing have the potential to deliver peak demand savings of real value in displacing scheduled generation if implemented automatically on direct space and water heating, air conditioning and local generation. Dynamic pricing also has the potential to reduce peak demand by means of shifting the demand of lighting and some appliances. If carried out automatically by means of lighting reduction and appliance use inhibits, it would have real and reliable potential to displace scheduled generation. The amount of demand displaced by dynamic and real time pricing is difficult to quantify and depends on what customers will permit in terms of temperature changes introduced in heating, water and air conditioning systems and in inhibits applied to appliances and the amounts of cost savings which result. However, ballpark estimates made in the previous sections suggest that perhaps an average of 1 to 3 kW demand reduction per household could be achieved with the implementation of a range of TOU pricing and control measures. An average demand reduction of 2 kW per customer has been used in later evaluations of costs and benefits of TOU pricing.

5 FIELD TRIALS AND RESULTS OF TOU PRICING

There have been relatively few empirical studies carried out on the impact of Dynamic and Real Time pricing on smaller customers. However, there is a large literature focused on price elasticity estimates for tariff based TOU rates. These estimates can be used to estimate responsiveness to Dynamic pricing, since many forms of Dynamic pricing simply expose customers to higher prices during varying time periods. When such prices are in effect, these estimates can be used to estimate changes in usage by comparing the higher dynamic price with the base price in the same manner that TOU Tariff pricing impacts are estimated by comparing peak period and base period prices.

Literature surveys estimate price elasticity for energy use at –0.14, indicating that a doubling of the on-peak to off-peak price ratio results in a drop of 14% in the corresponding energy use. This elasticity does however vary with the presence or absence of major appliances in the household. Households with no major electric appliances have an elasticity of –0.07. Households with all major electric appliances have an elasticity of –0.21.

However, these demand elasticity figures only provide crude approximations to what is likely to actually take place in practice and be sustainable over the long term. This is especially true for demand side measures aimed at automatic disabling of appliances and persuading customers to agree to these measures.

A number of field trials have been carried out in participating countries to measure customer responsiveness to a range of TOU pricing incentives.

5.1 Tariff TOU Pricing Trials

A field trial carried out in Finland had the objective of using price as a means to influence electricity demand in such a way that customers benefit from cheaper night-time electricity use and the supplier benefits from decreased power purchase costs. The target group was 25,000 smaller customers in the Nokia area. From these about 1200 were potential customers for Tariff TOU pricing having annual consumptions over 12000 kWh.

In September 1996 all the 25,000 customers obtained a leaflet describing the time of use tariff option. The aim was to create a positive attitude toward using the time of use rate instead of the old flat rate tariff. In addition, a letter was sent to the target group whose yearly electricity use was large enough for the new TOU rate to be an economically sound option. For the smaller energy consumption customers, a new tariff without time differentiation (Basic Tariff) was offered and bigger customers were offered the TOU rate.

Table 2 below shows the old flat tariff and the new flat and TOU tariffs.

Table 2

Tariff type	Monthly fixed charge Euro	Energy price, €/kW h	
		Day	Night
Old tariff	**21.7**	**0.046**	**0.046**
Basic Tariff	**5.3**	**0.054**	**0.054**
Time of Use	**14.5**	**0.058**	**0.024**

Marketing of TOU Tariff Pricing

Marketing material to promote the tariffs consisted of general information about the new tariff options as well as individual calculations of the economic impacts on electricity bills for those customers which had been purchasing electricity on the old tariff. The utility aimed at having personal contact by telephone with every customer to whom a letter had been sent in order to discuss the rate change. In those cases where the customer remained passive, the utility took the initiative.

Promotion of TOU rates to households using direct electric space heating and having a hot water boiler was carried out. Before the marketing campaign, the customers using the flat rate tariff were offered a new structure flat rate tariff with a lower fixed charge and higher energy charge or a new TOU tariff.

Some 400 changed from the old flat tariff to the new flat tariff during the first part of 1996. In the first year 130 customers changed to the TOU rate based tariff. By the turn of 96/97 there were still over 100 customers considering the profitability of the change.

The most important technical parameter affecting the bill savings was the size of hot water boiler which, in most cases, was in the range of 200-300 litres. This size class is suitable for exploiting the electricity price difference between day and night.

The cost to customers consisted of the control system installation which was partly site dependent and thus difficult to estimate in advance. The utility paid the cost of the switching clock (some 120 €). Detailed simulations of typical households revealed that the savings per households were about 260 €/annum.

Wood Use Enhancement Trial

This project carried out in Finland measured customer response to price substitution incentives and the tolerance to inconvenience. The project aimed at activating the use of wood in support of electricity for domestic space heating during system peak load periods. Two different approaches were tested.

In the first group, information displays were installed to inform customers of the time periods the use of wood, rather than electricity, was preferred by the

System Operator. Three factors were measured as hourly average values: the surface temperature of the wood-burning stove (to find out when it was used), electricity consumption and outdoor temperature. In addition, the amount of wood used was estimated by the participants themselves filling in a form.

The second group obtained in advance an amount of money equal to their yearly electricity bills and their electricity price was doubled for the test year. If the electricity consumption did not change, their economic balance did not change either: the net payment equalled that of the previous year. However, if they used less electricity than before then they obtained an economic benefit and vice versa.

In the group with the displays, the outdoor temperature compensated electricity use between 1995 and 1996 decreased by 8% and the night-time use of electricity increased from 65% to 68%. A detailed time-series analysis of each participant showed an average of 15% of the wood energy replaced electricity but the variations were large: from 6% to 47%. These savings resulted from customers wishing to assist the System Operator in delivering a secure electricity supply as well as achieving minor financial savings.

In the doubled energy price group, the majority of participants did nothing but paid the doubled energy bill with the advance payment. There were some who bought wood or new electric equipment, had a boiler repaired etc. For these participants, the outdoor temperature compensated electricity consumption decreased by 21% and, at the same time, the share of night-time electricity use increased from 59% to 66%.

The results indicate that doubling the price of electricity provides only a minor incentive for customers to reduce electricity use. However, for those motivated to save electricity, it resulted in them changing the timing of their electricity end use and also in increasing their use of wood for heating.

These studies indicate that promotion of electricity saving measures and persuading customers that their actions are helping the common good is a more powerful motivator than the relatively small financial savings. However, whether the savings as a result of manual actions are sustainable over the longer term needs to be proven.

5.2 Dynamic TOU Pricing Trials

A field trial has been carried out in Finland applying dynamic pricing to different types of customers. For 90–180 hours per year the price was 5 to 10 times higher than the normal base rate. During the rest of the year the price was reduced slightly so that the annual bill without changes in consumption would be the same as before.

Customers were provided with “traffic light” displays with a green light indicating normal price, a yellow light provided a pre-warning one day before the possible high price period, and a red light indicating that the high price was in operation. Communication with customers was based on Distribution Line Communication (DLC) technology and telephone lines. Consumption was measured on an hourly basis. The total number of customers participating in the trial was 130. The main results are as follows:

- Normal residential and agricultural customers (37 customers). Decreased demand by on average 21% in the evenings during the high price hours compared with previous demand.

- Residential customers with electric heating (33 customers). Decreased demand on average by 31% during the morning and evening peaks.

- Service sector (schools, offices, etc.) and small scale industry (59 customers). Decreased demand by on average 2-8% during high price hours.

In all these cases the load reduction did not influence the normal comfort of customers. The reduction was carried out manually. However, the feedback indicated that if this pricing policy was to be continued, customers wanted automatic switching of the loads.

Another field trial of the application of dynamic prices to smaller customers has just started in Finland. Electricity company, Turku Energy, has a product where pricing is based on the hourly spot price of Nord Pool (spot price + fixed margin). It uses hourly metering for larger customers but is offered to small customers without hourly metering with a flat rate price used for billing.

The trial comprised 15 small customers with electric heating (about 20,000 kWh/a or more) and 5 large service buildings/multifamily houses.

Prices were known the afternoon before the operational day with customers able to see the prices on the web-site. Customers could also predefine the alarm price levels for switching. If the price alarm level was exceeded, the customer received a message by mobile phone or e-mail. The price information was downloaded to customer automation systems which optimised energy use based on varying prices. Meters are remotely read and bills are based on hourly consumption and Dynamic prices for larger customers and a flat rate for smaller customers. Meter reading is usually via telephone lines

The objective of the field trial is to:

- Understand how Dynamic pricing based on hourly spot prices affects customer behaviour
- Demonstrate how building automation and home automation can take into account dynamically varying electricity prices and single rate metering
- Estimate the economics of dynamic pricing at smaller customers compared with TOU tariff pricing
- Demonstrate the possibilities/potential of selling the demand side to the markets, the market rules and technology

- Estimate the potential for demand side participation in the residential and service sectors

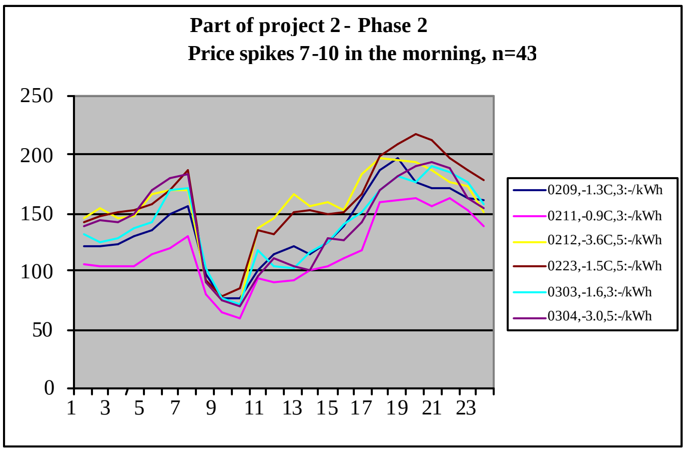
A field trial of Dynamic TOU pricing has also been carried out in Sweden to understand smaller customer manual responses to TOU pricing messages.

In the project, the 45 participating domestic customers were offered possible savings up to a maximum 140 Euro per year. The supplier announced price spikes (0.3, 0.5 or 1 Euro/kWh) for a total of 40 hours per year (in the winter). Maximum savings could be realised by reducing demand by more than 70% during those hours. If a customer did not take any action during the spikes, the financial result were cost neutral compared to costs using normal tariffs.

Among the participating domestic customers were a mix of different heating systems. In the group, there were also customers with oil/combinations furnaces as well as firing with wood. Households with no alternative heating were also represented.

Each participant was provided, before the start of the project, with advice on how to temporarily reduce consumption and what kinds of actions would significantly reduce load. In total, price spikes were announced 15 times for a total of 39 hours. Customers were informed about the spikes via text messages on their cellphones the day before the spike occurred (this simulated warnings at times of spot price publishing).

Households adjusted their indoor temperature a few degrees, without experiencing any significant losses of comfort. Over time, customers learned how to reduce their load and have also dared to reduce it increasingly. In the coming winter, the project enters a second phase when, hopefully, another distribution area, also employing TOU metering, in another part of the country, will be added.



Total consumption and reductions (kWh) among studied households at six different occasions during the winter 03/04. Price spikes were announced for hrs 07-10. Total population: 43.

The project is carried out by Esselcon in Skanör on behalf of Elforsk Market Design. It is also included in a proposal to the EU, which Elforsk has made together with (among others) Entro/Effektpartner (Norway), Energy Savings Trust (UK) and Lithuanian Energy Institute (Lithuania).

Two utilities in the USA, GPU and American Electric Power, conducted small-scale pilot programs on smaller customers using two-way communication and demand control technology called TransText. The TransText device allowed the creation of a fourth, critical price period in which the price of electricity rose to a much higher level. The number of hours during which this price can be charged is small (e.g. 100-200 hours per year) and the customer knows what the critical price will be ahead of time, but does not know when the price will be changed.

Consumers are advised via a display when a critical period is approaching and it can be programmed so that the consumer thermostats can automatically adjust when prices exceed a predefined level. Results showed significant load shifting, with estimated demand reductions of 2-3 kW during peak periods and of 3.5-6.6 kW during critical peak periods. These critical peak reductions represented almost 60% of consumer peak load during the winter period. Other smaller trials produced similar results, showing elasticities that ranged from –0.31 to –0.4, significantly higher than the elasticities associated with traditional TOU rates.

Another example of mass-market dynamic pricing is provided by Gulf Power Company's Good Cents Select program which used dynamic pricing to obtain additional benefits beyond traditional TOU pricing. Under this voluntary program, smaller customers faced a three-part TOU rate for 99% of all hours in the year, where the peak period price is roughly 60% higher than the standard tariff price and approximately twice the intermediate price. For the remaining 1% of the hours, the option of charging a critical price period price equal to, more than three times the value of the peak-period price was included. The timing of this much higher price was uncertain. In conjunction with this rate, participating customers were provided with a programmable/controllable thermostat that automatically adjusted their heating and cooling loads and up to three additional control points in the home, such as water heating and pool pumps. The devices could be programmed to modify usage when prices exceed a preset level.

The results show that peak-period reductions in energy use over a two year period have equalled roughly 22% compared with a control group, while reductions during critical-peak periods have equalled almost 42%.

Diversified coincident peak demand reductions have equalled 2.1 kW in the summer and 2.7 kW in the winter. This voluntary program has been in place for less than a year with more than 3,000 large-use, smaller customers agreeing to participate. It hoped to attract 40,000 customers over the next 10 years, representing about 10% of the residential population. Participating customers pay roughly Euro 5/month to help offset the additional cost of the communication and control equipment. In a recent survey, the program received a 96% satisfaction rating.

Another example of dynamic pricing is provided by Electricite de France, (EDF), Tempo program, which has been in place since 1996. The program features two daily pricing periods, on-peak and off-peak. It also features day-of-the-year pricing. The year is divided into three day types. "Blue days" are the most numerous (300) and least expensive; "white days" are the next most numerous (43) and mid-range in price; and "red days" are the least numerous (22) and the most expensive.

EDF does not offer a fixed calendar of days but customers know what pricing colour will take effect the next day by checking a coloured, light display panel in the premises which provides 24 hours notice of high price days.

Another Dynamic Pricing trial in the USA was started in 2001. PSE designed and implemented a time of use (TOU) rate for its residential and small commercial customers. The rate involved four pricing periods. The morning and evening periods were the most expensive periods, followed by the mid-day period and the economy period. Unlike most TOU rates, which feature significant differentials between peak and off peak prices, PSE's TOU rate featured very modest price differentials between the peak and off peak periods, reflecting the hydro based system in the Northwest.

The peak price was about 15% higher than the average price customers had faced prior to being moved to the TOU rate and the off peak price was about 15% lower. To keep the rate simple, there was no seasonal variation in prices.

About 300,000 customers were placed on the rate, but they could opt out to the standard rate if they so desired. There was no additional charge to participate in the rate. The rate was designed to be revenue neutral for the average customer. During the first year of the programme, less than 0.5% elected to opt out of the TOU rate. Customer satisfaction with the rate was high. In focus groups, customers identified several benefits of the TOU rate besides bill savings, including greater control over their energy use; choice about which rate to be on; social responsibility and energy security. PSE also provided a web site for customers where they could review their load shapes for the past seven days.

One year after the start of the programme, the peak/off peak rate differential of the TOU rate was reduced from 14 Euro cents to 12 Euro cents per kWh. An additional monthly fee of 1 Euro a month, about 80% of the estimated variable cost of providing TOU meter reading, was levied on participating customers. Finally, each quarter PSE would notify customers of their savings (or losses) on the programme, and it would switch all customers to the lower cost rate (flat or TOU) in August 2003.

For 94% of the customers this report showed that they were actually paying an extra eighty cents per month by participating in the TOU pilot. This comprised of the difference between 20% of power cost savings and 1 Euro of incremental meter reading costs. This finding resulted in customers withdrawing from the trial so that it was finally cancelled.

Five simple lessons can be drawn from PSE's short-lived Dynamic TOU pricing programme:

- Customers do shift loads manually in response to a TOU price signal, even if the price signal is quite modest. According to an independent analysis, customers consistently lowered peak period usage by 5% over a 15 month period.

- It is important to manage customer expectations about bill savings.

- Customers should be educated on the magnitude of bill savings they can expect from specific load shifting activities. A variety of means can be used for providing this information to them, including letters, refrigerator magnets, a company Web site that provides a listing of load shifting activities and associated savings estimate, and a personal web site which they can consult for tracking their load shapes and savings.

- It is desirable to conduct a pilot programme involving a few thousand customers before offering a rate to hundreds of thousands of customers. The pilot should allow before/after measurements on participating customers as well as customers in a statistically representative control group. It should also feature multiple TOU prices, rather than a single price, in order to allow measurement of price elasticities. This information would allow the company to estimate the impact of future rates that are not included in the small pilot.

- Finally, and most importantly, any programme should make a majority of the customers better off, or it should not be offered.

Field trials of Dynamic TOU pricing have been carried out in the UK involving 400 smaller customers with combinations of storage and direct space heating and storage water heating.

A demand control algorithm (CELECT) applied to the heating system scheduled the charge and release of energy from the storage heating based on half hourly price messages, 24 hours ahead. The direct heating was used to support the heat output of the storage heating during low price times. A learning algorithm was included which learned the heat loss parameters for each house based on external temperatures. A major feature of the control regime was that it was automatic with no option for customers to override it. Consequently, although customers could switch it off and adjust thermostat set points, they could not switch heating on.

One of the trials of the Celect system was carried out by SWALEC (the Distribution Network Operator in South Wales) over the period 1996 – 98, as a part of the ETHOS project (a European trial of interactive services using

European Home System protocols). Over 100 houses were included in the trial. The aim was to reduce the overload on a rural distribution network, by avoiding the night peak which resulted from all storage heaters switching on at the same time. Reducing the overload would avoid or defer the need for expensive network reinforcement.

Cost reflective messages were broadcast to the houses, by either radio or Telephone (PSTN). PSTN allowed smaller customer groupings, which was advantageous in providing a wider spread of start times than was possible with radio and more accurate management of the demand. Communication inside customer premises used power line communication and EHS (now Konnex) protocol.

The trial showed a 25% reduction in peak demand, enough to avoid reinforcement costs. Householders reported an increase in comfort (especially in houses where storage heaters were undersized). Energy consumption was reduced by 15% and customer satisfaction was high.

The use of PSTN also allowed 2-way communication, enabling TOU metering data to be remotely collected. This was not used in the supplier, settlement process at the time but it clearly demonstrated the principle of dynamic pricing and TOU metering. The intention was to use the system with single rate metering and no customer override.

The Dynamic Pricing regime was also applied to a washing machine and dishwasher in customer premises to assess whether this was an approach which would be accepted by customers. The algorithm identified periods of sufficient duration to complete the wash cycle at lowest cost, based on estimated prices delivered 24 hours ahead. The appliances could be set to "energy saving" mode which made them responsive to energy price. However, customers had the option of overriding the controls and using the machines at any time. Consequently for these applications with customers able to use them at any time, TOU metering was required. Because the demand shift is optional, it is less predictable and secure as a demand side measure. However, customer reaction results from these applications are not available.

The Dynamic, continuously variable pricing and automatic demand profile shape change regime resulting from the application of Celect, was not acceptable at that time for use with profile settlements and required TOU metering. Consequently, although technically successful with high customer satisfaction, it was not rolled out into the market place because of the additional cost required for metering and processing the metered data.

Credanet

Credanet is a reduced version of the CELECT system which is marketed commercially in the UK for storage heating systems. It relies on intelligence at each storage heater to determine demand requirements and matches this with a relatively simple dynamic tariff message to determine when charge to the storage heaters is supplied. Power Line Communication is used inside customer premises.

This tariff based system produces a more predictable storage heater demand profile than Celect because demand is switched in defined time slots. These time slots can be changed dynamically using radio, PSTN or DLC communication external to customer premises, which allows the system to deal with some unscheduled system capacity shortages. However, profile settlements is able to accommodate the reduced variation in switching times compared to Celect, so that many Credanet systems are in use in the UK using profile settlements.

Also field trialled has been another system which has the flexibility to alter the storage heater, charge/temperature algorithm and include external ambient temperature in the charging regime. This system allowed different blocks of charge time to be made available during the day when prices are not too high and used DLC communication to control the switching. It is believed that at least one major supplier is currently interested in investigating the use of more dynamic, multi-charge periods within profile settlements. Although this is still at the theoretical investigation stage, the long term aim is to include the technique in the suppliers EEC (Energy Efficiency Commitment) target (a UK Government set target for energy suppliers to introduce energy saving and efficiency measures).

A field trial has also been carried out in Denmark of the EFFLOCOM system whereby customer equipment receives Real Time TOU price information and controls different elements of household demand based on preset parameters. More information on this system and room settings is contained in Section 6.3. The trial comprised:-

25 single family houses with direct electric heating:

- Consumption >16,000 kWh/yr
- Individual settings control the duration of interruptions
- 5 zones of electric heating within each house
- 3 price levels
- 2 time periods (morning/afternoon)
- Possible to override control
- TOU metering

Prices signal can be applied for a maximum of 100 hours per year:

- Triggered by spot prices
- Demand shift action is carried out according to the preset preferences set by customers and agreed in the household table.

An average reduction in demand per customer of 3 kW was obtained. Customers were satisfied with the heating performance of the system and would recommend it. Override possibilities were provided so that multi rate metering was needed in order to quantify the demand taken in the predefined time periods and to reward customers. It may be possible with more experience of customer long term behaviour with the scheme to consider a flat rate tariff for different levels of participation on the basis that customers will not override the system. This control methodology has the benefit that customers are able to set their individual and optional energy control profile which, once set, is automatically implemented by the System Operator. Consequently a reliable demand shift is more likely even though it is possible for customers to override the temperature controllers.

6 TECHNOLOGIES AND COSTS FOR TOU PRICING

Different methodologies are available and can be further developed for implementing TOU pricing based on Tariff, Dynamic and Real Time pricing at smaller customer premises. These deliver the motivator for customers to respond with manual and/or automatic demand switching. The more flexible and nearer to real time the price messages can be presented and acted upon, the more valuable they are to System Operators. The more automatic the response of demand to the price messages, the more predictable and reliable the demand changes are likely to be over the long term. Manual responses to price signals have value as demonstrated by the French Tempo tariff and others for example where coloured lights are used to inform customers of forthcoming high prices on a day ahead basis. However, under adverse weather conditions, for example, customers may ignore the price messages and not change thermostat settings.

It is important to recognise that TOU price or switching messages based on cost can be used to switch demand automatically at customer premises but customers can still be charged using a single rate tariff. This is particularly possible if no override of the automatic control is allowed so that single rate metering can be employed. Some such trial schemes are in operation in participating countries, as discussed in Chapter 5.

Single rate and multi rate metering are readily available commercially for smaller customers and will not be considered here from a technology perspective. The additional costs of multi rate metering and processing over single rate metering are included in the overall costing.

Price or demand switching messages for smaller customers can be applied to a range of loads depending upon the specific household. Potential loads are:-

- Storage heating, cooling and water heating (switch energy "in"/"out")
- Direct space heating (modify thermostat settings)
- Direct Water heating (modify thermostat settings)
- Direct Space cooling (modify thermostat settings)
- Embedded generation (start out of heat led regime)
- Fridges and freezers (switch off for short period)
- Washing machines (disable for period, change time schedule)
- Dish washer (disable for period change time schedule)
- Cooker (disable for period)
- Sauna, car heaters (disable for period)
- Direct electric showers (disable for period)

This list is not exhaustive but includes all types of loads from the point of view of application complexity, cost and implementation acceptability.

These loads are considered for demand shifting based on Tariff, Dynamic and Real Time pricing signals.

6.1 Tariff TOU Pricing

Various technologies are in place in participating countries to carry out TOU tariff based metering and demand switching with the most common using spring reserve time switches which are preset and can accommodate supply interruptions without requiring resetting. Various remote switching technologies are also used with most communication based on power line carrier, telephone and broadcast radio. These communication technologies allow a degree of flexibility in the switching times. Usually however only low data rates are available from installed communication systems so that only limited group addresses are possible and hence only limited different switching regimes. Communication infrastructures can allow some automatic switching of the optional demand such as reducing lighting and disabling appliances. However this requires "in house" communication between appliances and time switches or an external communication interface on each application. Remote switching of demand provides more reliable and predictable demand shift and hence increases its value to System Operators but is more expensive than manual switching.

6.2 Dynamic TOU Pricing

Dynamic Pricing has been field trialled in several participating countries to understand the potential and interest of customers in moving energy demand on a dynamic and relatively short time scale basis in order to save money. In order to implement Dynamic Pricing it is necessary to have at least a one way communication link between suppliers and customers. A two way communication link can be provided which allows more sophisticated control and monitoring of demand and also additional dialogue between customers and suppliers. As discussed in Chapter 2, dynamic pricing can be applied to all categories of demand by providing 24 hour notice of price changes. Consequently storage demand can be optimised in terms of selecting the lowest cost times to charge the heat store (space and water heating). Direct space and water heating and air conditioning can be controlled by reducing thermostat settings or switching off heating completely in selected rooms. Appliances and lighting can be controlled by applying inhibits to the use of specific items at high price times or reducing illumination intensity. If automatic control of these demands is allowed by customers with no override option, then single rate metering can be used for billing purposes. The overall TOU pricing methodology then becomes TOU Tariff pricing for billing purposes and TOU Dynamic Pricing for demand management. If an override possibility is allowed so that reducing demand is optional for customers then TOU metering will be required. Manual meter reading using hand held units is a feasible option with dynamic pricing.

Depending on the degree of control required in the premises, ie controlling the complete house demand from a single point or controlling individual rooms and appliances, different levels of communication are needed. If manual control of the demand is implemented, where customers respond, for example, to coloured lights which indicate approaching high cost times, then only simple one way communication to a single point in the premises, visible to customers, is needed. If automatic control of house storage demand is implemented, then only one way communication is required to the single point of control. However, improved comfort and increased savings are possible with communication to individual heaters. Communication media for all these applications have been provided using broadcast radio and power line communication in trials and commercial applications (Chapter 5).

Switching storage demand to optimise times and costs against dynamic pricing is easy for customers to accept because it is unobtrusive and provides improved heat delivery and comfort. It also allows smaller capacity storage heater devices to be used, compared with those using TOU tariff switching. The switching of direct heating and cooling, appliances and lighting is much more intrusive for customers and something they would evaluate in accepting the cost saving possibilities. Communication for these systems, where selected rooms in the premises are reduced in temperature or specific appliances are disabled, will be more extensive. Either a “home communication bus” or direct access by broadcast radio to each device is needed. “Home bus” communication can be provided using pico cellular radio, power line carrier or twisted pair communication media. Consequently communication between system operator/supplier and customer applications is via both external and internal to the premises communications for large scale implementation. Because with these schemes, override options are more likely to be requested by customers, multi rate metering may also be a requirement. If the frequency of over ride is minimal then it may be possible to use single rate metering. If the frequency of override is not minimal then the demand shift is of much less value to system operators in terms of reliability and implementation costs will also be greater.

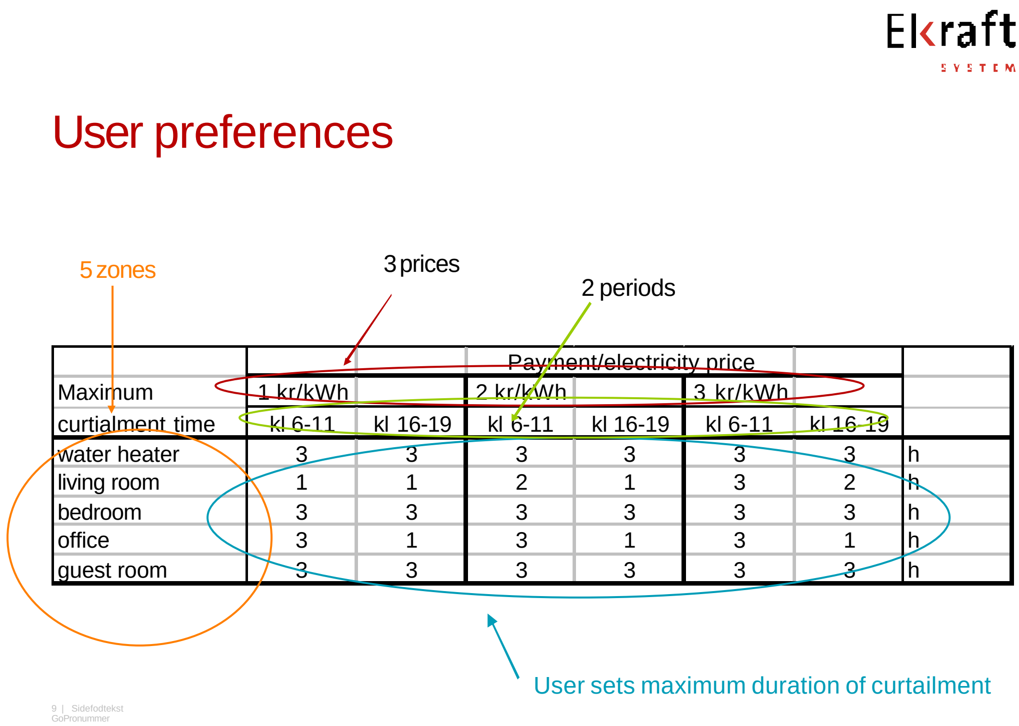
6.3 Real Time TOU pricing

Real time pricing is the most attractive and valuable arrangement for managing demand from a System Operator perspective but the most difficult for customers and demand to respond to. The smaller customer demand which can respond effectively to Real Time Pricing is direct heating and cooling demand where thermostat settings can be modified and embedded generation can be directly started. Appliance and lighting switching is likely to require some advanced notice to customers. Storage heating requires a pricing profile in order to charge the store at lowest cost so that real time pricing is unlikely to be viable. Any control using Real Time Pricing has to be automatic. Thermostat setting management by automatic means in response to price with no customer override or the conviction that customers will in general not over ride the settings or switch on supplementary electric heating, would provide valuable “stand by capacity” for System Operators. If no override option is provided for customers or they did not exercise that option, then single rate metering may be possible, leading to lower implementation costs.

A project which seeks to exploit customer responsiveness to Real Time Pricing (EFFLOCOM) is targeted at specific end uses and includes a dialogue between customers and suppliers/System Operators based on an interactive Internet model. In this model customers are able to define what direct space heating and cooling, automatic changes to thermostats they would accept relating to different rooms in the houses. They can also define what loss of heating, maximum time restrictions they will accept for individual rooms. These restrictions and controls are implemented based on real time energy prices so that different restrictions can be applied in principle to different energy end uses without any notice period being given. Different payment levels for different times of interruption are included to motivate customers.

A list of example settings is shown in Table 3.

Table 3



Maximum curtialment time	Payment/electricity price						
	1 kr/kWh		2 kr/kWh		3 kr/kWh		
	kl 6-11	kl 16-19	kl 6-11	kl 16-19	kl 6-11	kl 16-19	
water heater	3	3	3	3	3	3	h
living room	1	1	2	1	3	2	h
bedroom	3	3	3	3	3	3	h
office	3	1	3	1	3	1	h
guest room	3	3	3	3	3	3	h

An estimated investment of the order of 600 Euro per customer (1,000 houses) is required in order to implement the system. It may be possible to reduce this by 50% with large scale roll out.

6.4 Communications for TOU Pricing

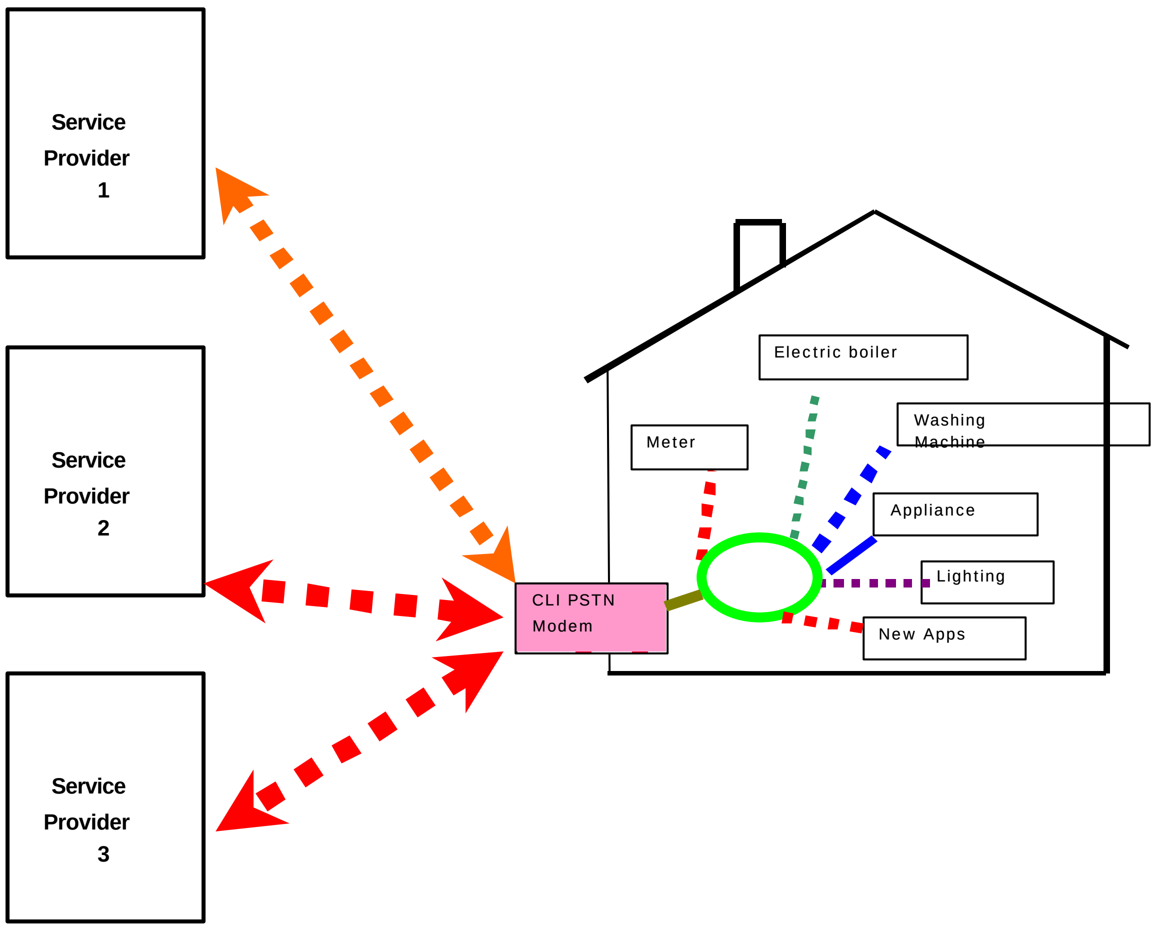
Implementation of TOU, Tariff, Dynamic and Real Time energy pricing regimes require different levels of control, communications and response times in order for them to operate effectively and deliver the appropriate demand shift. Previous sections showed that Tariff, Dynamic and Real Time pricing overlap if no override option is allowed by customers. Consequently a fixed kWh price can be paid by customers even though the end uses are responding to dynamic price messages. In order to implement TOU Tariff, a communication system is required to download price messages. In order to carry out billing for Dynamic pricing with an override option, multi-rate metering is needed. For space heating and cooling and water heating, it can be argued that customers will not in general override automatic thermostat reductions if these reductions are only present for relatively short periods. However, if the disabling of appliances is also included, together with saunas, car heaters and "direct on" showers, with override options, then multi-rate metering will almost certainly be required.

Communication systems needed to deliver TOU Tariff and Dynamic Price messaging regimes comprises one way, broadcast media with the ability to deliver broadcasts on a zoned basis. This ability to activate demand changes in zones or blocks allows finer control of demand and is valuable to System Operators. Individual and unique communication to each customer is not required, nor is confirmation that the commands have been activated at customer premises. Demand switching errors due to failed communication etc., can be identified through the multi-rate metering. If there is no optional override and single rate meters are used, errors would not be detected and it would, in principle, be possible for customers to receive energy at any time at the lower tariff rate.

Communication to individual end uses within customer premises in order to activate thermostat setting changes or disable appliances requires careful consideration because it is a critical element in overall system costing. Communication outside customer premises between System Operator, Supplier and customer can be based on broadcast or cellular radio, power line, pager or telephone media with relatively long response times allowed, in order to deliver prices. Communication inside customer premises can take the form of pico cellular radio, power line or twisted pair. It is also possible for controlled end uses to directly receive the external broadcast radio signals. The choice between using the external broadcast communication system to deliver price messages directly to individual end uses or to use a separate but linked internal communication home bus depends on cost. It also depends on whether other customer services are likely to share the communication system. These could be home security, medical and alarm monitoring for example. If other services are included in the communication infrastructure in order to share the system and help offset the costs for TOU pricing applications, then separate, internal to the premises communication bus systems are is likely to be more flexible and overall, lower in cost.

These gateway linked internal and external communication architectures have been studied extensively for the delivery of wide range of customer services. A typical architecture is shown in Fig 9 where different service providers are shown having exclusive access to individual applications and services inside customer premises. One of these services would be TOU pricing and demand management; another could be appliance, remote diagnostics, etc.

Fig 9
Networked Home Customer Services Infrastructure



The alternative architecture where end uses receive external to the premises communication directly without using a home bus is used in the Efflocom field trial.

Communication for this system is two-way, as well as including a zoned broadcast capability. Consequently, it can be accomplished using two way radio, power line or fixed wire telephone systems. Response times for the demand control can be relatively long so that high data capacity is not a requirement for the remote control. However, it would be a constraint in carrying out the customer/supplier dialogue in order to establish the demand shift, end use parameters. Customers would not accept a slow and time-consuming process in order to carry this out. Consequently GPRS radio or fixed wire telephone are the only realistic external communication options able to provide adequate data rates. Traditional switched telephone communication systems could have some difficulties in delivering the broadcast function to large numbers of customers. However, packet switched telephone systems now being installed would be able to deliver rapid broadcast functions.

6.5 Costs of TOU Pricing

A detailed study carried out within the DSM Agreement Task 2 into the cost of providing widescale, comprehensive services to customers considered the business proposition of providing smaller customers with communication and infrastructure for the delivery of a range of services including energy management. It considered the provision of communication systems inside and outside customer premises and the issues of gateways to link them together. Costs for the provision of customer energy services were analysed on the basis of the requirement to deliver aggregated services to large populations of customers sharing a common communication infrastructure. The average cost per customer for communication gateways and simple in house communication was 40 Euro per year. Additional costs associated with individual end uses being able to respond to communications are not included in this cost. These are incremental costs associated with each end use and the installation of additional control nodes. The average incremental cost for each control node was estimated to be only a few Euro if installed in energy end uses during manufacture and made in volume production. Consequently, the cost of providing communication infrastructure to deliver TOU Tariff and Dynamic pricing and probably Real Time pricing to several individual end uses is of the order of 50 Euro per year. Based on a 10% discount rate for 10 years, this results in a capital cost of 50 x 6.7 = 335 Euro per customer. If broadband communication is required in order to achieve high data rates and fast response times for Real Time pricing then higher costs will be incurred.

These above costs do not include metering and meter data processing costs. The major costs associated with TOU metering are those required to process the data. The total additional metering costs of TOU pricing are estimated to be tens of Euros per annum per customer. This has been estimated as an additional capitalised cost of 100 Euro. Consequently, an average capitalized cost of 435 Euro per customer has been estimated for providing TOU pricing with and without TOU metering for large populations.

6.6 TOU Pricing and Profile Settlements

A major issue associated with Dynamic and Real Time TOU pricing is how to deal with dynamic profile changes in profile settlements systems. Profile settlements systems differ within participating countries, especially in the number of profiles used and how the profiles are developed. However, they all rely on predictability of load shape for average smaller customers. This defined and stable profile shape, together with the known modifiers such as sunrise and sunset times etc is used to apportion demand against time for different suppliers at Grid metering points. Variable and difficult to quantify profiles, such as those generated by Dynamic and Real Time TOU pricing make profile settlements as presently operated, difficult to maintain. Resulting errors between summated profiled customer demands and measured total demands in existing profile settlements systems are apportioned among suppliers. One way round this problem is to insist that all demands which are responsive to dynamic pricing must be TOU metered. This could be half hourly, hourly or some other value. This requirement would increase the costs of implementing TOU Dynamic pricing because of the additional metering complexity. It would also increase the costs of implementation because of the additional costs of processing the TOU metering data in profile settlements systems. This is estimated for the UK at more than 100 Euro per customer per year.

Another approach is to consider the development of new profiles which include average responses for different categories of customer to TOU Dynamic price messages. This could be possible for automatic actions and is already included in the UK settlements system for dealing with remotely and variable time switched storage demand. In this system, switching times can be varied within defined limits and the demand switched at the same time as the two rate meter register is switched. There is no customer override option. The variable profiles for these customers are calculated automatically by the settlements system on the basis that the switching commands issued to the end uses are also input to the settlements system. Experience has allowed new profiles to be generated using this additional demand switching data which are agreed by all suppliers.

This approach could be expanded to include all demands using TOU Dynamic and Real Time pricing which are automatically switched, as long as no optional override is allowed. Optional switched demand or demand switching which allows customer override and which they use are unlikely to be possible within profile settlements systems except by using TOU metering.

The most difficult and expensive part of introducing new profiles is deriving the profiles themselves. Existing profiles have been determined using statistically large populations over a long period of time so as to minimize intrinsic error. It will be difficult to achieve statistically meaningful samples to allow derivation of profiles for all of the varieties of domestic switchable demand including micro-scale generation. The costs of deriving a profile have been roughly estimated, by a study group in the UK, as Euros 140,000-700,000.

Self generation has the potential to radically alter the import profile of smaller customers. The simplest arrangement for dealing with generation output which is mainly used on site is to use a single direction meter. In this case, when generation displaces imports, it is valued at the import price. When generation results in export, the customer-generator is not paid for it. Revised profiles would be required by suppliers which would be specific to different generator technologies.

To enable domestic and other micro-scale generation to be given benefit for exports, significant changes to the settlement system are required with profiles being created to cater for each type/size of domestic and other micro-scale generation.

6.7 Acceptability of Demand Response Strategies

A summary, Table 4, has been produced to indicate the various impacts of TOU pricing regimes, their relative acceptability to customers and System Operators and comparative costs.

Table 4

	Customer Interest		Customer Choice	Implement-ation Cost	Value to SO	Data presentation costs
DEMAND RESPONSE STRATEGY	Thermo -stats	Appliances				
Manual Demand Shifting						
a) No notice of prices						
- Limits on times/price	-	-	****	*	**	****
- No limits	-	-	****	*	**	****
b) 24 hrs notice of prices						
- Limits on times/price	**	**	****	*	*	***
- No limits	*	*	****	*	*	***
Automatic Demand Shifting and Customer Override						
a) No notice of prices						
- Limits on times/price	**	*	***	***	**	****
- No limits	*	-	***	***	***	****
b) 24 hrs notice of prices						
- Limits on times/price	***	**	****	***	*	***
- No limits	**	**	****	***	**	***
Automatic Demand Shifting and No Customer Override						
a) No notice of prices						
- Limits on times/price	**	-	*	**	***	***
- No limits	-	-	*	**	****	***
b) 24 hrs notice of prices						
- Limits on times/price	**	*	*	**	**	**
- No limits	-	-	*	**	***	**

7 COSTS AND BENEFITS OF TOU PRICING

Quantifying the viability of different TOU pricing mechanisms for use as motivators for demand changes is complex especially across the range of participating countries and their different generation supply mixes. In the first instance, there has to be enough reduction in supply side costs as a result of TOU pricing to provide customers with adequate financial incentives to participate. Other requirements of the demand side changes resulting from TOU pricing are that they must be very reliable and predictable in order to have high value to System Operators. Consequently allowing optional demand shift and regimes where customers have the ability to override automatic demand switching instructions even for customers with TOU metering is likely to be of lower value than no override option systems. In fact, as discussed in earlier chapters, no override option and single rate metering have advantages from both reliability of demand shift and lower metering costs. However, customers are likely to require more financial incentive to participate in no option TOU pricing regimes. It is possible to make overview and approximate financial comparisons between construction of supply side capacity and motivating and delivering demand side reductions through TOU pricing. This has been carried out by comparing an average cost per kW of building generation, transmission and distribution capacity against an average cost of installing control and metering equipment to deliver 1kW of demand shift and motivating smaller customers to accept the inconvenience.

Chapter 2 presented an estimated average demand of possibly 2kW per customer being available on peak with the potential to be shifted off peak. Different levels of reliability and predictability have been shown to apply to different TOU pricing regimes and implementations using manual/optional and automatic/remote control. However, the demand shift made available to System Operators must be aggregated to form a load block which can be activated using simple instructions. The less inconvenience caused to customers, their lifestyle and comfort, the more acceptable will be the process. Consequently, the frequency of implementation of the shift in demand required to be moved to off peak times in order to deliver the effective capacity saving needs to be assessed.

A study carried out in Spain identified the times for which system demand exceeded different levels, Fig 10.

Fig 10
Annual Duration of use (hours) of generation capacity 2004/2005 (maximum 100 hours)

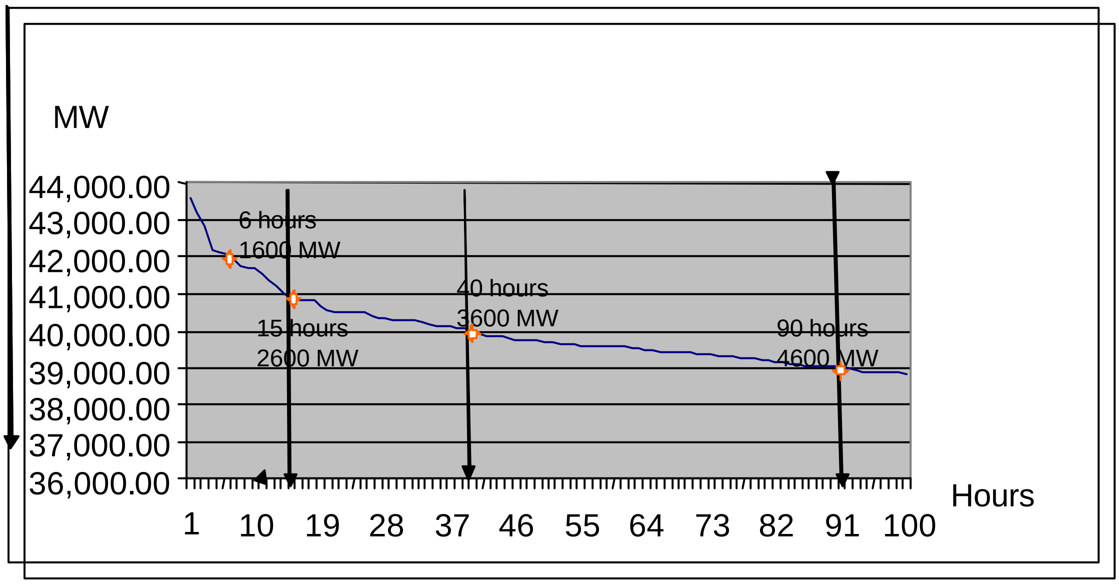


Fig 10 shows the number of hours per year when different elements of generating capacity were called upon to operate in Spain. Particularly significant is the fact that 2000MW of generation operated for a total of only nine hours per year and represented 6% of maximum demand. (During mild winters, the 2000MW of generation does not generate at all). For the UK, system demand exceeded 90% of its system peak (53.4GW) for 170 hours. Assuming the nine hours of operation in the case of Spain, were all to supply peak demands, it is critical to consider whether this demand could have been supplied reliably and effectively by demand side reductions. In the context of this report this means in response to TOU pricing for smaller customers. Assuming the technology were available to download price messages and carry out the appropriate switching and controls and that customers were suitably motivated to participate in the process, the demand shift would be possible. In order to deliver 2000 MW of demand reduction, based on 2 kW per customer, one million smaller customers would need to be included in the process and equipped with energy management technology. Issues of metering and profile settlement become critical in terms of costs and acceptable processes for the implementing TOU pricing.

The equation for viability, therefore, is whether the financial savings resulting from not building generation and network capacity are greater or less than the costs of implementing TOU pricing and providing sufficient motivation to customers to reliably deliver 2000 MW of demand reductions.

For the purpose of this study, the generation capacity has been considered as being built predominantly to meet the 2000 MW of peak demand although, in practice, it would also be available at other times to meet contingencies and deliver import or export reactive. This is the best case scenario for demand side viability. The cost of providing the 2000 MW from the perspectives of generation, transmission and distribution network investment valued at a cost of 1000 Euro per kW in Chapter 1, is Euros 1000 x 2 x 10^6 = Euros 2000 millions.

In order to remove the 2000 MW demand by reducing the demand of smaller customers for nine hours per year, with an average reduction of 2 kW per customer, 1 million customers need to be involved. The average capital cost per customer for providing Tariff, Dynamic and Real Time pricing demand reduction (from chapter 4) is 435 Euro. This cost allows control to be implemented of direct space heating and cooling, saunas, showers, water heating, lighting and some appliance disabling. Disabling of appliances could take the form of householders setting completion times for items such as dish and clothes washing machines when they are used. Generally with no inhibit applied, the machines would start as late as possible so as to complete the full cycle by the preset completion time. If a inhibit had been applied and the set cycle time included the time of the inhibit, the cycle would be automatically rescheduled to start earlier so as to be completed before the inhibit time.

The total capital cost of removing the 2000 MW of demand using smaller customer demand management via TOU pricing and switching is therefore, 1 million x 435 = €435 million. Consequently a reduction in capital expenditure of €2000 million - €435 million = €1565 million is delivered. Consideration has then to be made of whether this saving shared among participating customers is sufficient to motivate them to participate and to compensate for the reduced flexibility of the demand side compared with a generator. The maximum incentive payment available to each customer either in the form of a reduced tariff or a single payment is € 1565 million divided by one million customers = €1565 per customer. This single payment would be available to provide an incentive for smaller customers to participate in 2 kW of demand reduction for 9 hours per year. The available incentive payment money would be less if payment for the loss of flexibility were deducted in order to pay for some extra generation capacity. On the basis of a 10% discount rate for 10 years, this results in an annual incentive payment of €234 per customer.

An important factor in comparing demand side control and management systems with despatched generation is equipment lifetimes. Generation, transmission and distribution equipment have lifetimes in excess of 40 years. Remote control equipment has a lifetime of no more than half that. This would reduce the incentive money available to motivate smaller customer participation.

A large scale promotional campaign would also be required to educate and motivate customers to participate. This campaign is likely to require on going investment to encourage and motivate customers especially where optional demand shift is required.

Although the above comparison of costs and value of TOU pricing to deliver demand reductions uses ballpark estimated values, it does indicate the sort of financial incentives that may be available to encourage customer participation. The major issue therefore is whether an annual payment to smaller customers of €234 would be sufficient to motivate them to deliver 2kW of demand reduction for 9 hours per year.

Sensitivity consideration of the costs and value figures used, suggest that where an option is provided for customers to override the remote switching, TOU metering will be required and hence incur higher costs than with single rate metering. Where no override option is provided, single rate metering should be possible for billing purposes even with Real Time TOU pricing and hence incur lower costs. However, it may be more difficult to obtain customer participation if no override is allowed particularly for appliances and lighting. Countering this is that the demand shift is less predictable if an override is allowed and hence of less value to System Operators. Consequently higher incentive payments should be possible for non over ride regimes. The field trials included measures ranging from single tariff and synchronised demand switching with no override using one way communication to a two way communication dialogue arrangement whereby customers agree a complete switching regime and parameters together with override and remote TOU metering. Obviously the implementation costs are greater for more sophisticated control and metering systems.

8 CONCLUSIONS

This study has estimated the financial viability of implementing different TOU pricing regimes by equating reliable and flexible demand shift with scheduled generation, transmission and distribution network construction costs. In order to do this, the study has estimated the costs of implementing TOU pricing regimes per kW of demand shift and the ball park cost of new supply side construction. Based on comparison of these estimates, on average, annual payment to customers €234 is available as an incentive and motivator for them to participate. This is very much a global figure and will vary greatly in specific situations in different countries. The figure is also a probable maximum as it includes a mix of direct electrically and none electrically heated households. It will be reduced if customers with direct space and water heating are not included. However it is likely that TOU implementation routes would be based initially on targeting customers with the largest demands.

The study has identified that, other than direct space and water heating demand shift by reducing thermostats, air conditioning, lighting and some domestic appliances are end uses which could in principle be moved off-peak. Customer small scale micro generation also has an important role to play in generating outside normal heat led times and made responsive to TOU energy pricing.

A critical issue which influences the development of TOU pricing using Tariff, Dynamic and Real Time pricing is whether customers are provided with an option to override the remotely/automatically switched demand signals. If customers have the option not to deliver the demand shift and they exercise it, then the reliability of the potential demand shift is questionable and of less value to System Operators. If the option to override automatic demand shift signals is not provided, then single rate metering is possible. However, customers are likely to require greater financial incentives to participate in some elements of demand shifting, particularly appliance controls, if an override option is not provided.

Reducing peak demand for very few hours per year has been shown to have a large benefit in terms of reducing system capacity requirements.

The financial benefits from this study which are available to motivate smaller customers to participate in TOU pricing, are not great. No definitive studies have been identified which have analysed customer reaction to the disabling of appliances for short periods a few times per year and the financial incentives required. No studies have been identified which have analysed the possibility and acceptability of reducing lighting levels again for a few hours a few times per year. These studies need to be carried out together with assessments of the financial incentives needed to obtain customer participation, particularly with no override options allowed.

This study has identified that thermostat reductions of direct space and water heating and air conditioning for a few hours per year could make significant contributions to reducing system peak demand. It has also been identified that in future, small scale micro generation could easily be controlled on the basis of TOU pricing to reduce unscheduled peak demands.

Communication has not been identified as a major technical constraint on the implementation of TOU pricing but is very important in the financial viability of these measures. Low cost communication is needed based on both broadcast radio technologies which communicate directly to end uses or on hybrid systems which use separate external and internal to the premises communication systems for the control of the many different services and energy end uses. These separate systems are linked together using customer gateways. The choice between these two approaches depends mainly on economics and whether the communication infrastructure is shared by other services, such as alarms and monitoring etc. The more the cost of communication and control can be reduced, the more feasible it becomes to apply demand management to smaller end uses.

Consideration has been given to relating together the three main types of TOU pricing: Tariff, Dynamic and Real Time. The study has shown that the difference between them becomes very unclear if no customer override option to the demand shift is allowed and a single rate tariff is used for billing. With this scenario, some customer end uses could respond automatically to real time prices (thermostat reduction), yet be billed using a single rate tariff. If a customer override option is allowed, then multi rate metering is required for billing purposes. The question of whether the cost savings associated with not providing customers with an override option are sufficient to overcome customer reluctance to participate needs further study. The answers to this question are likely to be end use specific. Thermostat set point changes are relatively unobtrusive. Lighting reduction and appliance disabling are obtrusive and would cause customer inconvenience. This inconvenience would be small if only applied for a few hours per year. However extensive marketing campaigns would be required to persuade customers to participate.

Results of Field Trials of dynamic pricing identified that automatic intervention is preferred for shifting demand rather than customers being required to take manual actions.

Tariff, Dynamic and Real Time TOU pricing are all likely to be viable for direct space and water heating thermostat control. They may also be viable for centrally controlled air conditioning systems, micro generation, saunas and direct electric showers. On their own, remote switching of lighting and appliances is probably not be viable, both from the size of the demand and also the inconvenience caused to customers. However, with very effective marketing and the requirement to inhibit demand for only very few hours per year, customers may be persuaded to participate. It may also be possible to inhibit demand for very short times for each customer but apply it in a sequence to a larger population of customers so as to achieve an overall demand reduction for a longer period.

The study has identified that all three methods of TOU pricing can deliver demand reductions depending on the end use demand being controlled. All three methods have value to System Operators. The important factors in this regard are that the demand shift is reliable and predictable. The more available the demand shift is, the more valuable it is as an alternative to scheduled generation. Consequently Real Time pricing with automatic demand reduction is the most valuable because it can be used to deal with unscheduled peaks. However, it is likely to be the most expensive to implement. Combinations of Tariff, Dynamic and Real Time pricing can be considered where different demands in the same household are managed by each mechanism.

9 RECOMMENDATIONS

- Evaluate the potential and acceptability of different end use, demand management and customer participation methodologies with no customer override and single rate metering.

- Evaluate the possibilities for lighting management taking into consideration the limitations imposed by energy efficient lights.

- Evaluate the potential for using micro CHP and fuel cells to respond to TOU prices and reduce the demand to be met by scheduled generation.

- Estimate the required financial and motivating incentives needed to obtain customer participation in obtrusive demand side measures for relatively few hours per year.

- Evaluate combined Tariff, Dynamic and Real Time, TOU pricing in a single household and applied to different elements of the demand with different notice times and controls.

- Quantify the feasibility of developing profile settlement systems to deal with Dynamic TOU pricing and demand changes.

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Overview of the International Energy Agency (IEA)
and the IEA Demand-Side Management Programme

The International Energy Agency

The International Energy Agency (IEA), established in 1974, is an intergovernmental body committed to advancing security of energy supply, economic growth, and environmental sustainability. The policy goals of the IEA include:

- diversity, efficiency, and flexibility within the energy sector,
- the ability to respond promptly and flexibly to energy emergencies,
- environmentally-sustainable provision and use of energy
- development and use of more environmentally-acceptable energy sources,
- improved energy-efficiency,
- research, development and market deployment of new and improved energy technologies, and
- undistorted energy prices
- free and open trade
- co-operation among all energy market participants.

To achieve those goals, the IEA carries out a comprehensive program of energy cooperation and serves as an energy forum for its 26 member counties.

Based in Paris, the IEA is an autonomous entity linked with the Organization for Economic Cooperation and Development (OECD). The main decision-making body is the Governing Board, composed of senior energy officials from each Member Country. A Secretariat, with a staff of energy experts drawn from Member countries and headed by an Executive Director, supports the work of the Governing Board and subordinate bodies.

As part of its program, the IEA provides a framework for more than 40 international collaborative energy research, development and demonstration projects, known as Implementing Agreements, of which the DSM Programme is one. These operate under the IEA's Energy Technology Collaboration Programme which is guided by the Committee on Energy Research and Technology (CERT). In addition, five Working Parties (in Energy Efficiency, End Use, Fossil Fuels, Renewable Energy and Fusion Power) monitor the various collaborative energy agreements, identify new areas for cooperation and advise the CERT on policy matters.

IEA Demand Side Management Programme

The Demand-Side Management (DSM) Programme, which was initiated in 1993, deals with a variety of strategies to reduce energy demand. The following 17 member countries and the European Commission have been working to identify and promote opportunities for DSM:

Australia	Italy
Austria	Japan
Belgium	Korea
Canada	The Netherlands
Denmark	Norway
Finland	Spain
France	Sweden
Greece	United States
	United Kingdom

Programme Vision: In order to create more reliable and more sustainable energy systems and markets, demand side measures should be the first considered and actively incorporated into energy policies and business strategies.

Programme Mission: To deliver to our stakeholders useful information and effective guidance for crafting and implementing DSM policies and measures, as well as technologies and applications that facilitate energy system operations or needed market transformations.

The Programme's work is organized into two clusters:

- The load shape cluster, and
- The load level cluster.

The 'load shape" cluster includes Tasks that seek to impact the shape of the load curve over very short (minutes-hours-day) to longer (days-week-season) time periods. The "load level" cluster includes Tasks that seek to shift the load curve to lower demand levels or shift loads from one energy system to another.

A total of 15 projects or "Tasks" have been initiated since the beginning of the DSM Programme. The overall program is monitored by an Executive Committee consisting of representatives from each contracting party to the Implementing Agreement. The leadership and management of the individual Tasks are the responsibility of Operating Agents. These Tasks and their respective Operating Agents are:

Task 1 International Database on Demand-Side Management &
Evaluation Guidebook on the Impact of DSM and EE for Kyoto's GHG Targets
Harry Vreuls, NOVEM, the Netherlands

Task 2 Communications Technologies for Demand-Side Management - *Completed*
Richard Formby, EA Technology, United Kingdom

Task 3 Cooperative Procurement of Innovative Technologies for Demand-Side Management – *Completed*
Dr. Hans Westling, Promandat AB, Sweden

Task 4 Development of Improved Methods for Integrating Demand-Side Management into Resource Planning - *Completed*
Grayson Heffner, EPRI, United States

Task 5 Techniques for Implementation of Demand-Side Management Technology in the Marketplace - *Completed*
Juan Comas, FECSA, Spain

Task 6 DSM and Energy Efficiency in Changing Electricity Business Environments – *Completed*
David Crossley, Energy Futures, Australia Pty. Ltd., Australia

Task 7 International Collaboration on Market Transformation
Verney Ryan, BRE, United Kingdom

Task 8 Demand-Side Bidding in a Competitive Electricity Market - *Completed*
Linda Hull, EA Technology Ltd, United Kingdom

Task 9 The Role of Municipalities in a Liberalised System *Completed*
Martin Cahn, Energie Cites, France

Task 10 Performance Contracting *Completed*
Dr. Hans Westling, Promandat AB, Sweden

Task 11 Time of Use Pricing and Energy Use for Demand Management Delivery
Richard Formby, EA Technology Ltd, United Kingdom

Task 12 Energy Standards
Frank Pool, New Zealand

Task 13 Demand Response Resources
Ross Malme, RETX, United States

Task 14 White Certificates
Antonio Capozza, CESI, Italy

Task 15 Network-Driven DSM
David Crossley, Energy Futures Australia Pty. Ltd, Australia

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