Evaluation of the effects of a tariff change on the Italian residential customers subject to a mandatory time-of-use tariff

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Keywords

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Abstract

Time-of-use (ToU) tariff at two-part rate periods has become the default condition for residential customers in Italy since July 2010. It provides for variable prices of electricity depending on the hour of the day: the price is higher during "peak hours" (the hours between 8 am and 7 pm on working days) and lower during "off-peak hours" (all remaining hours); the price difference between the two groups of hours was fixed and equal to 10 % during the transitional phase (July 2010–December 2011), while, starting from January 2012, the final ToU tariff has come into force with a larger price difference deriving from the electricity market hourly price profiles.

In order to evaluate the effects of the switch from the transitional to the final ToU tariff, RSE selected and analysed a group of 1,000 customers, statistically representative of the whole Italian population. Their electricity consumption data have been measured by smart meters every 15 minutes and have been made available by the corresponding Distribution system operators (DSOs), starting from January 2011.

Moreover, the customers are undergo a set of periodic computer assisted interviews, aimed at gathering information about the electric appliances each family owns and about their usage on the different days of the week and at different times of the day.

The paper will present the results of the evaluation of the effects of the switch from the transitional to the final ToU tariff, taking into account in particular the shift of the loads from peak to off-peak hours.

The paper will also describe the statistical model, built upon the information gathered by the interviews, which RSE implemented with a specific software tool based on Monte Carlo simulation; such model has been used to assess both the contribution of each appliance to the overall load curve and the effects of moving its usage to different periods of the day. The results have shown little impact of the consumption shift and a negligible modification of consumers' habits; this is caused, in particular, by the tiny price difference between peak and off-peak hours. The consequent benefits are analysed both from the final user's point of view and from the whole Italian system's one.

Introduction

The largest part of Italian residential users have always been billed with a flat (time undifferentiated) tariff: such tariff undoubtedly presents several advantages from the DSO's point of view, because all the costs related to metering and billing are significantly reduced with respect to other forms of billing.

Flat tariffs are also easy to handle by the final users because they have to deal with a constant price during the day and do not have to adapt their consumption in order to face the abundance or scarcity of electricity on the market, in particular decreasing it during high demand hours. A tariff which were more adherent to the real prices of electricity on the market was necessary, in order to start spreading among residential customers the awareness that electricity has now become a commodity subject to the rules of the market: this will favour their active participation in the demand-response, increasing the overall efficiency of the electricity network in Italy.

Therefore, in order to gradually expose customers to time dependent costs of electricity, the Italian Authority for Elec-

Table 1. Energy price difference.

Energy price difference between ToU and flat tariff during the transition period [c€/kWh]	
Peak hours	+0.592
Off-peak hours	-0.297

Price difference between transitional ToU and flat tariff (VAT at 10 % excluded).

tricity and Gas (AEEG) introduced a mandatory Time-of-Use tariff with two rate periods, which has come into force since July 1st 2010. It provides for two groups of hours: the price is higher during "peak hours" (the hours between 8 am and 7 pm on working days) and lower during "off-peak hours" (all the remaining hours) with respect to an hypothetical flat tariff.

This will let the customers start to acquire the capability to respond to the signals coming from the electricity networks and markets and their actors by suitably modulating their consumptions, especially in order to face all the issues related to the increasing penetration of renewable energy sources in the last years.

Time-of-Use (ToU) tariffs present a certain degree of correlation between the price of electricity paid by the customers and the costs of its supply, even if the larger the length of the time periods, the more averaged are the price signals. This allows the customers to cooperatively respond but, at the same time, the customers who are not capable to adjust their demand according to the price, are somehow protected.

A 18-months transition period was established (from July 1st 2010 to December 31st 2011) in order to make the transition from flat tariff more gradual: during these transitional months the price difference between peak and off-peak hours was limited (transitional ToU tariff), while, starting from January 1st 2012 the final ToU tariff has come into force with a larger price difference, according to the prices of electricity on the competitive market. Table 1 shows, for example, the values of energy price differences in force during the transition period.

DESCRIPTION OF THE PANEL

In order to analyse the effects of the switch from the transitional to the final ToU tariff among residential customers, RSE started a research project 00 in collaboration and under the patronage of the AEEG: the project has involved a group composed of 1,158 household users ("sample of families"), statistically representative of the whole Italian population and RSE has acquired, through the respective DSOs, their consumption data with a detail of 15 minutes.

Data acquisition started in January 2011 and is currently on-going, in order to cover the period before and after the switch from the transitional to the final ToU tariff; the period covering the shift from the flat tariff to the ToU tariff had not been monitored, because it occurred before January 2011. A classification of the "sample of families" based on their geographical distribution is shown in Figure 1.

As you can see, the geographical distribution of the "sample of families" is consistent with the distribution of the Italian population, as surveyed by the Italian National Institute of Statistics (ISTAT) in 2011 0. The average size of the families and the type and size of their homes are consistent with the ones of the average Italian family, as surveyed in 0; unfortunately no other characteristics are available about the families due to privacy restrictions.

The sample of families also underwent a set of periodic computer assisted interviews, aimed at gathering information about the electric appliances each family owns and about their usage on the different days of the week and at different time of the day. The enquiry (called "Energy Monitor") 00, started in October 2010 and currently on-going, has been carried out in collaboration with GfK-Eurisko.

This set of very detailed information allowed us to carry out a much deeper analysis about the impact of the switch from the transitional to the final ToU tariff and monitor possible changes in users' behaviour, taking into account in particular the shift of the loads from peak to off-peak hours.

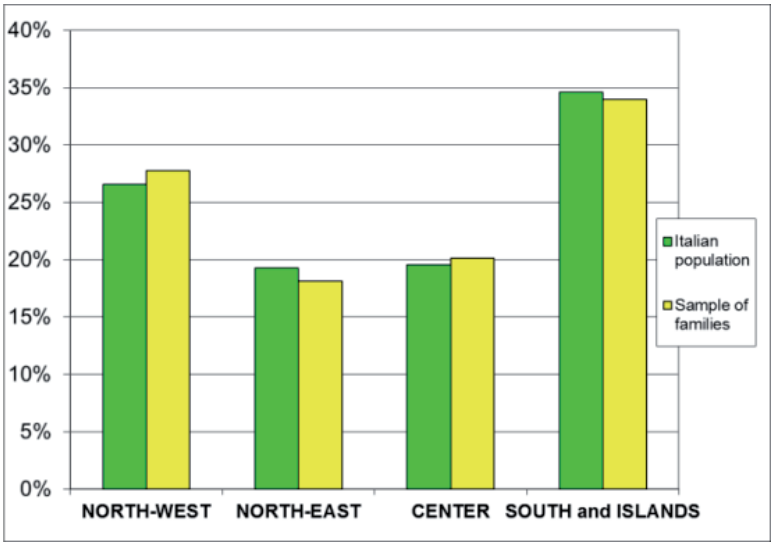

Figure 1. Comparison between the geographical distribution of the Italian population and the sample of families.

Effect of the tariff change on the load curves

VARIATION OF THE LOAD CURVES AFTER THE SWITCH FROM THE TRANSITIONAL TO THE FINAL TOU TARIFF

We now present the comparison between the load curves of 2011 and 2012, in order to evaluate the effects of the change from the transitional to the final ToU tariff. We have selected 3 different types of days (working days, Saturdays and holidays) and three seasons (winter, spring and summer), as the load curves relative to the last months of 2012 are not available yet. The load curves of the average working day are shown in Figure 2.

The load curves of 2011 and 2012 are very similar, both in their shape and in their average values. Starting from them, the average energy shift from peak to off-peak hours has been evaluated; the results are shown in Table 2.

We can see that there is a shift of consumption from peak to off-peak hours in summer 2012, while the shift goes in the opposite direction in the other seasons. The reduced amount of the shift confirms, however, the fact that the average load curve during working days is substantially unchanged after the switch from the transitional to the final ToU tariff. The load curves relative to the average Saturday and holiday in the different seasons are shown in Figure 3 and Figure 4.

As you can see, the load curves of Saturdays and holidays of 2011 and 2012 are very similar: this means that the switch from the transitional to the final ToU tariff did not affect neither the level or the shape of the load curves.

Effect of the tariff change on the consumption habits

VARIATION OF THE CONSUMPTION HABITS AFTER THE SWITCH FROM THE TRANSITIONAL TO THE FINAL TOU TARIFF

Even though we have realized that load curves are unaffected by the tariff change, it is interesting to analyse if and how customers' consumption habits have been affected by such change. We expect, of course, little variations in their consumption habits, which is consistent with the fact that the load curves have not significantly changed. The results of the comparison of the habits are shown in Tables 3–8.

As you can see, there is a small shift of the probability of use of the washing machine, of the dishwasher and of the oven from off-peak to peak hours, which is the opposite direction the ToU tariff was supposed to induce the customers to comply with.

On the other hand, the probability of use of the tumble dryer and the water heater during off-peak hours has increased; however the diffusion of such appliances among residential customers in Italy is much lower than the diffusion of the washing machine or the dishwasher. There is also an increase of the probability of use of the air-conditioner during off-peak hours but the amount is very low. Therefore, the effect of the shifted consumption of the three previous listed appliances is almost negligible on the average load curve.

All the values of the consumption shift presented here are, however, comprised in the interval [-2%;2%]: this shows that the effect of the tariff change from the transitional to the final ToU tariff has had little or no effect on the habit of consumption of the consumers composing the panel of families.

The largest part of residential customers' consumptions used to occur, in fact, during off-peak hours even before the introduction of the ToU tariff, thus further reducing the amount of consumption which is in principle shiftable from peak to off-peak hours. Moreover, the small values involved suggest also that they may be the results of random factors, rather than to the change of tariff, which confirms the negligible effect of such change.

Table 2. Average energy shift.

Winter 2012 – Winter 2011		Spring 2012 – Spring 2011		Summer 2012 – Summer 2011	
Δpeak hours	Δoff-peak hours	Δpeak hours	Δoff-peak hours	Δpeak hours	Δoff-peak hours
0,39%	-0,39%	0,50%	-0,50%	-0,56%	0,56%

Average energy shift from peak to off-peak hours in the average working day of different seasons of 2012 with respect to 2011.

DESCRIPTION OF THE SIMULATION TOOL "SCUDO7"

The set of very detailed information made available by the research has been used to tune a statistical model of the residential consumptions, in order to assess the contribution of each appliance to the overall load curve. This model has been used to analyse the amount of consumption shift from peak to off-peak hours which might be necessary in order to obtain a relevant monetary benefit for the final user; monetary incentives are, in fact, powerful tools from the customer's point of view, even if, as we shall see better further on, other approaches to prompt the customers' response may be more suitable. In any case, the increased capability of the customers to face time-dependent prices of electricity will bring many benefits to the whole Italian system, which may be quantified and, in some way, transferred to the customers.

The model has been implemented with a software tool called SCUDO7 00 (*Simulazione dei Carichi degli Utenti DOmestici – Simulation of the loads of residential users*) based on Monte Carlo simulation; it simulates a household by characterizing all the appliances with input data such as their technical characteristics, the dissemination in the households and the average number of usages during the day, for example.

The output of the simulation consists in the final load curve and its decomposition into the contribution of the different appliances, with all the parameters necessary to fully characterize such a contribution. We have decided to analyse a working day in winter, because this type of day is often among the critical ones from the point of view of the electric system. To this aim, we have selected the average load curve of a working day in winter 2011, shown previously, and we have calibrated the model on such a load curve.

The information necessary to build the model have been extracted from the "Energy Monitor" enquiry and from other data acquired by RSE during his long experience in dealing with the habits and characteristics of domestic users.

RESULTS OF THE SIMULATION

Figure 5 shows the comparison between the reference measured load curve relative to the average working day in winter extracted by the "sample of families" and the simulated load curve obtained by the model.

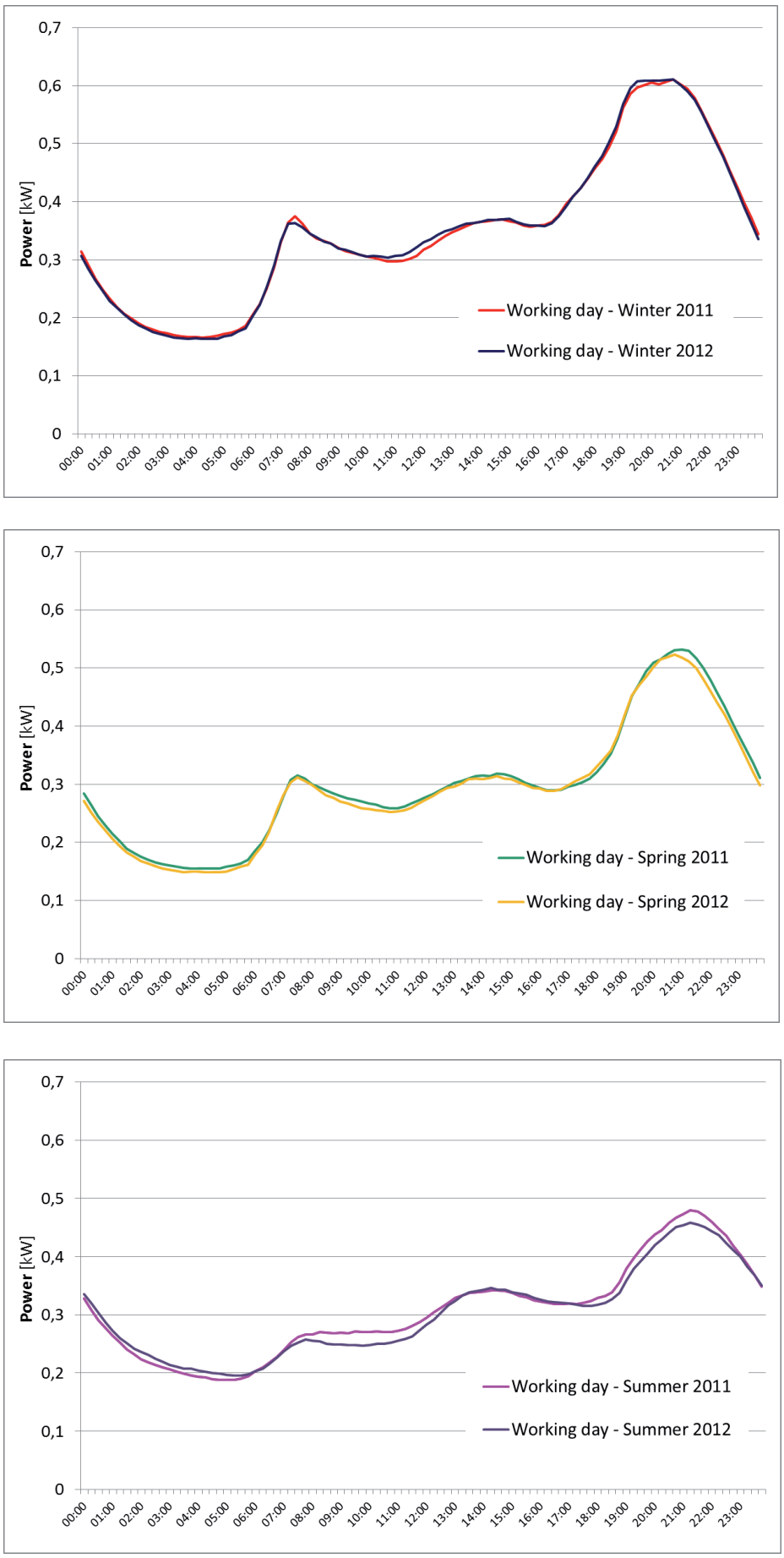

Figure 2. Comparison between load curves of the average working day relative to different seasons in 2011 and 2012.

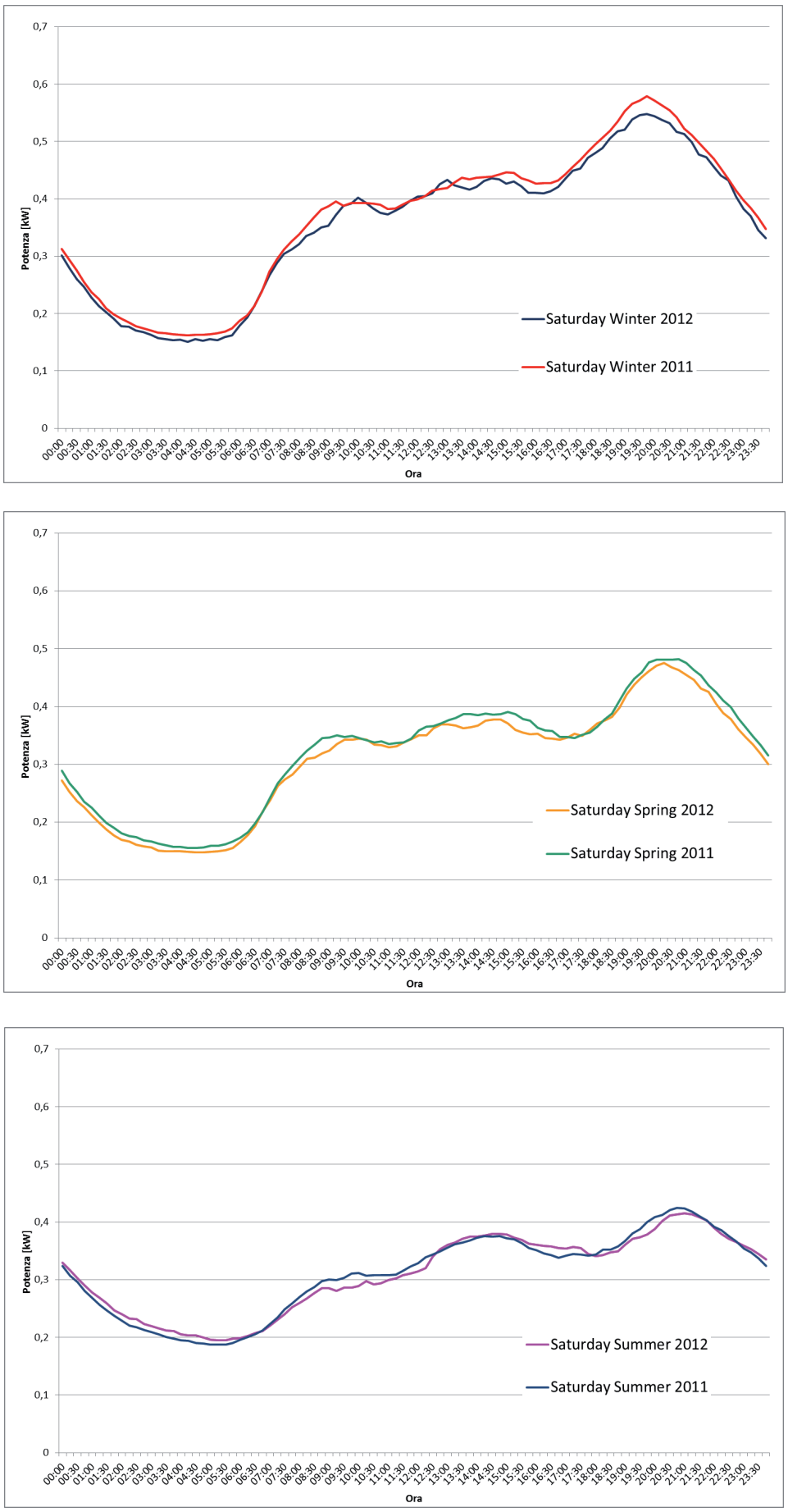

Figure 3. Comparison between load curves of the average Saturday relative to different seasons in 2011 and 2012.

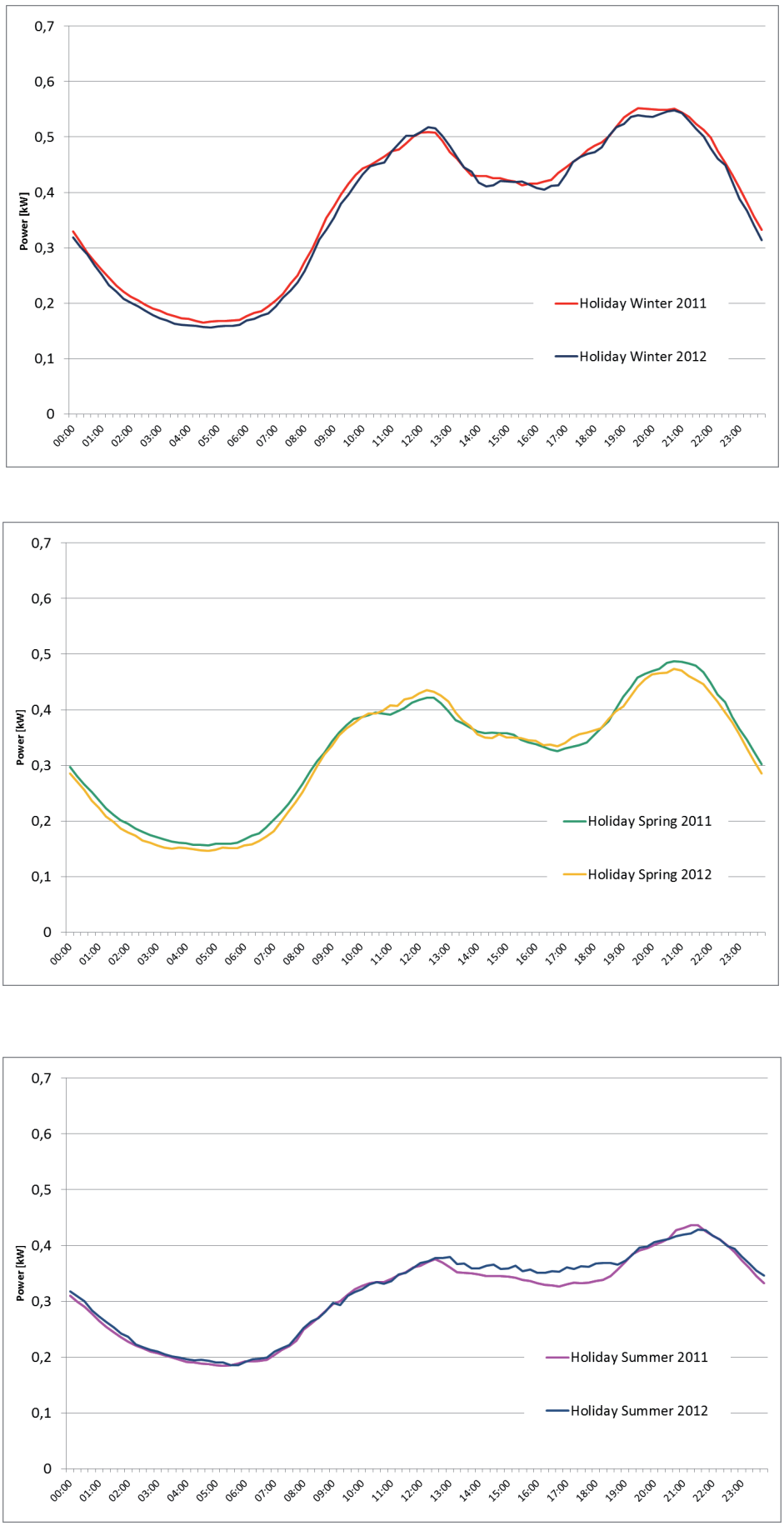

Figure 4. Comparison between load curves of the average holiday relative to different seasons in 2011 and 2012.

Table 3. Washing machine probability of use.

	PEAK HOURS	OFF-PEAK HOURS
Transitional ToU tariff (2011)	30,95%	69,05%
Final ToU tariff (2012)	31,53%	68,47%
Δ	0,58%	-0,58%

Analysis of the variation of the probability of use of the washing machine before and after the tariff change.

Table 4. Dishwasher probability of use.

	PEAK HOURS	OFF-PEAK HOURS
Transitional ToU tariff (2011)	18,94%	81,06%
Final ToU tariff (2012)	19,65%	80,35%
Δ	0,71%	-0,71%

Analysis of the variation of the probability of use of the dishwasher before and after the tariff change.

Table 5. Oven probability of use.

	PEAK HOURS	OFF-PEAK HOURS
Transitional ToU tariff (2011)	32,22%	67,68%
Final ToU tariff (2012)	33,02%	66,98%
Δ	0,80%	-0,80%

Analysis of the variation of the probability of use of the oven before and after the tariff change.

Table 6. Tumble dryer probability of use.

	PEAK HOURS	OFF-PEAK HOURS
Transitional ToU tariff (2011)	28,47%	71,53%
Final ToU tariff (2012)	26,72%	73,28%
Δ	-1,76%	1,76%

Analysis of the variation of the probability of use of the tumble dryer before and after the tariff change.

Table 7. Water heater probability of use.

	PEAK HOURS	OFF-PEAK HOURS
Transitional ToU tariff (2011)	21,28%	78,72%
Final ToU tariff (2012)	22,60%	77,40%
Δ	-1,32%	1,32%

Analysis of the variation of the probability of use of the water heater before and after the tariff change.

Table 8. Air-conditioner probability of use.

	PEAK HOURS	OFF-PEAK HOURS
Transitional ToU tariff (2011)	22,68%	77,32%
Final ToU tariff (2012)	22,56%	77,44%
Δ	-0,12%	0,12%

Analysis of the variation of the probability of use of the air-conditioner before and after the tariff change.

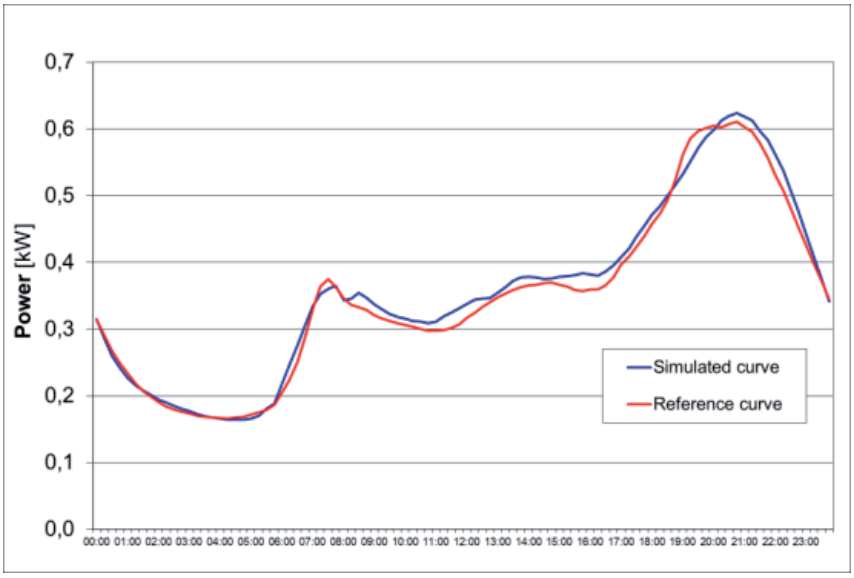

Figure 5. Comparison between measured and simulated load curve relative to the average working day in winter.

Table 9. Results of the simulation.

	Simulated load curve	Reference load curve	Δ
$P_{average}$ [W]	357,3	349,1	-2,3%
P_{max} [W]	623,8	610,3	-2,2%
P_{min} [W]	164,0	166,1	-1,3%

Comparison between some significant parameters of the measured and simulated load curve relative to the average working day in winter.

As we can see, there is a good correspondence between the results of the simulation and the real load curve: the absolute value of the difference between the average power of the two load curves is, in fact, less than 2.5 %, while the difference between the maximum and minimum power is equal to, respectively, to about -2.5 % and -1.5 %. This shows the capability of the software tool to simulate real load curves and therefore the reliability of its prediction about real users' behaviour. The decomposition of the simulated load curve into the contributions of the various appliances is shown in Figure 6.

As we can see from Figure 6 the base of the graph is constituted by the refrigerator, the freezer and the water heater: they represent a stable and constant value of consumption during the day, to which the consumption of the other appliances is superimposed. The other appliances do not have a uniform load curve during the day.

There are three main peaks: the larger occurs in the evening (from 7.30 pm to about 10:30 pm), while the other two occurs in the early morning (from 7:30 am to 9:30 am) and during lunch time (from 11:30 am to 1:30 pm).

The minimum value of the load curve is reached during the night, from 2:30 am to 5:30 am: such structure with three peak and a large valley is the typical shape of the residential load curve during winter.

The largest contribution to the evening peak comes from the washing machine (21,4 %), the water heater (12,7 %), the refrigerator (11,7 %), the television (9,2 %), the oven (8,6 %), the lighting appliances (7,7 %) and the dishwasher (5,8 %).

The early morning peak is mainly constituted by the contribution of the water heater (19,9 %), the refrigerator (21,6 %), the washing machine (11,9 %), the lighting appliances (4,7 %) and the electric oven (15,2 %).

We now suppose to increase the probability of use of some electric appliances during off-peak hours: the selected appliances are deferrable in principle, in the sense that their use can be shifted during different periods of the day, up to a certain extent. They are listed below:

- washing machine;
- dishwasher;
- iron;
- water heater;
- vacuum cleaner.

The use of all the other appliances, such as the television or air conditioning appliances, obeys to other priorities which go beyond the mere monetary incentive to the consumer.

The result show that, with a 5 % increase of the probability of use during off-peak hours with respect to the peak hours, the average saving for the final user is about €0.32/year; with an increase of 10 % of the probability of use, the saving is about

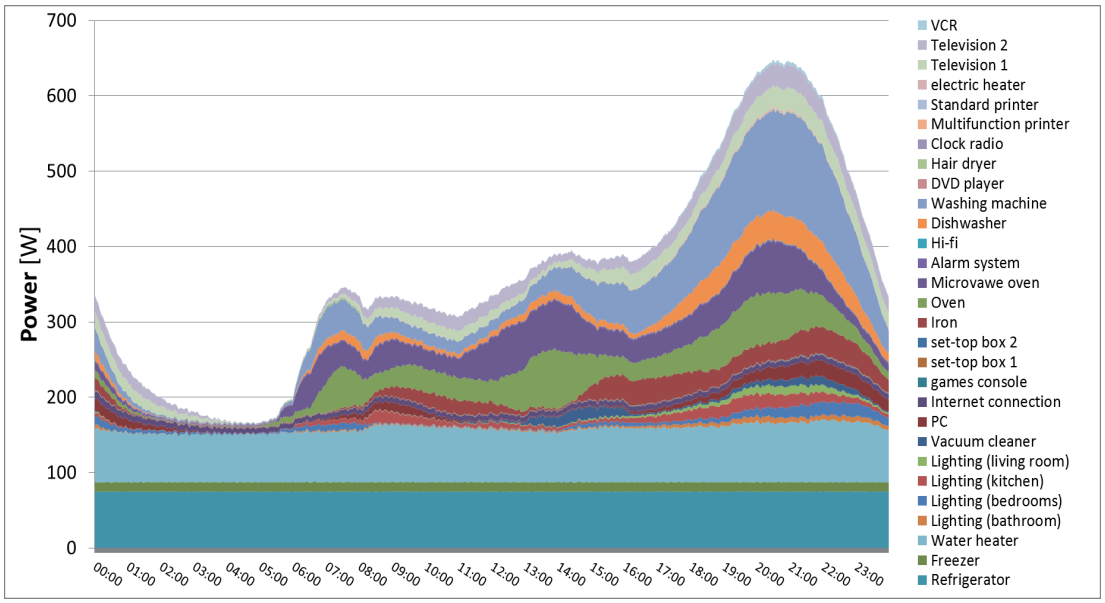

Figure 6. Contributions of the various appliances to the aggregated load curve in the average working day in winter.

€0.65/year, while, with a 20 % increase, the saving reaches €1.29/year: the potential savings deriving from the modification of the habits of usage are therefore quite small even in the best case.

Figure 7 shows the simulated load curve with a 20 % probability increase during off-peak hours and compares it with the reference load curve. As we can see, the load curve is unchanged during night hours, while there is an increase in the value reached by the morning and evening peaks, because a higher percentage of the consumption are concentrated in such hours; correspondingly, the values reached by the curve are lower during the central part of the day, which is mainly composed of peak hours.

In reality, shifting the use of the appliances listed above might be quite difficult for the final user, because it might require a significant variation of his/her habits, which is not always feasible; besides, the available power might not be enough to sustain many appliances working in the same interval of hours, especially because most of the off-peak hours during working days (from 7 pm to 8 am) occur just in coincidence with the evening peak, as we can see in the average load curve in Figure 6. Programmable appliances might represent a possible solution, because their functioning can be suitably scheduled during off-peak hours, in order to reduce the overlap among them.

Conclusions

The first part of this article has been devoted to analyze the effects of the switch from the transitional to the final ToU tariff among residential customers in Italy. The comparison of the load curves before and after the tariff change has shown that such effects have been negligible, because the load curves are very similar both in their shape and in their average values: this means that consumers' habits have not been affected by such tariff modification, as the consumption shift from peak to off-peak hours has been very low. The main reason which has prevented a larger shift among the customers can be attributed to the price difference between peak and off-peak hours, which is very low in comparison to other ToU tariff experiences in other countries 0.

A detailed comparison of the habits of usage before and after the tariff switch has shown, in fact, that the percentages of the shifting of the main deferrable electric appliances are all comprised in the interval [-2%;2%].

We have therefore analysed the theoretical percentage shifting which might be necessary to achieve a benefit larger than €1/year for the final user: it has resulted to be around 20 %, which does not represent an unfeasible possibility for the average domestic user; the monetary benefit of €1/year, however, is not certainly enough to justify customer's effort to modify his/her habits, also because, as it has already been said, the percentage of residential customers' consumption during off-peak hours is quite large even before the introduction of the ToU tariff.

Besides, a reduction of the price difference between peak and off-peak hours is currently taking place because the current subdivision does not fully reflect the order deriving from the average market prices of electricity in the different hours: this is due to several factors, in particular the diffusion of distributed generation in Italy, and makes the price of some off-peak hours larger than the price of peak hours. Changing the composition of the group of hours may allow a larger price difference among them and therefore make the price signal stronger. To such an aim, the AEEG has proposed a modification of the current ToU tariff structure 0, in order to make the tariff more effective.

ToU tariff could be accompanied by the "Critical peak pricing": it consists of a huge increase of the price of electricity for short periods of time; the shorter the duration of the periods, the higher the price difference: these two factors allow a significant load shifting from peak hours with respect to ToU tariffs 0.

Other approaches can also be adopted, such as using other benefits different from the mere monetary ones in order to prompt the residential customers to be more active actors inside the electric network. Only when such process is complete, it will represent a fundamental milestone in the transition towards the smart grids.

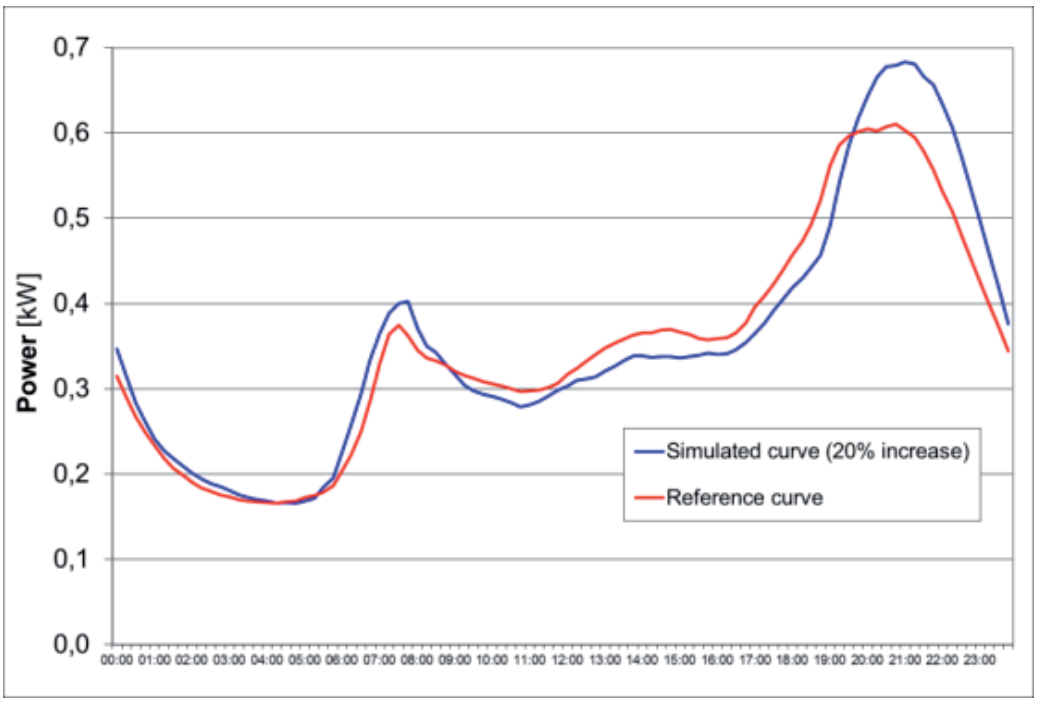

Figure 7. Comparison between measured and simulated load curve with a 20 % probability increase during off-peak hours relative to the average working day in winter.

References

S. Maggiore, "Impatto su comportamenti e consumi delle famiglie di un sistema di prezzi biorari dell'energia elettrica", RSE reference number 11000398, 2011, available on http://www.rse-web.it.

S. Maggiore, "Impatto su comportamenti e consumi delle famiglie di un sistema di prezzi biorari dell'energia elettrica", RSE reference number 12000915, 2012, available on http://www.rse-web.it.

ISTAT, 15th Italy General Population and Housing census, 2011, available on http://dati.istat.it/.

A. Faruqui and J. Palmer, "The Discovery of Price Responsiveness - A Survey of Experiments involving Dynamic Pricing of Electricity", SSRN Working Paper Series, 2012.

Deliberation 216/2012/R/EEL, "Orientamenti per la revision della struttura per fasce orarie dei corrispettivi PED applicatiai clienti domestici in maggior tutela", AEEG, 2012.

A. Faruqui and J. Palmer, "Dynamic Pricing and Its Discontents: Empirical Data Show Dynamic Pricing of Electricity Would Benefit Consumers, Including the Poor", Regulation Vol. 34 No. 3, 2011.

A. Faruqui and S. Sergici, "Household response to dynamic pricing of electricity – A Survey of 15 Experiments", Journal of Regulatory Economics Vol. 38 No. 2, 2010.

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