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The Impact of Price Incentives on Household Electricity Demand

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Abstract

Power grids in many European countries are under strain during peak hours, especially during summer heat waves. In Poland, the Transmission System Operator is searching for methods to mitigate this problem through the use of multipart tariffs. The main objective of this study is to investigate the influence of multipart tariffs on consumption and heterogeneity of electricity consumption among households. This study is based on an experimental survey that tests a demand response to Time of Use tariffs and to a voluntary reduction scheme. The test took place in Kalisz, the city in central Poland. It provided 15-minute metering data (n=1285). This was accompanied by socio-economic data collected by PBS polling agency in the survey of more than 1700 households. Parametric test and Latent Class Model were used to verify the stated hypotheses. Multipart tariffs proved effective in reducing electricity consumption during peak hours. The obtained results suggest that households shift their electricity consumption from weekdays to weekends. It also provides an insight into patterns of electricity usage among households.

Keywords: Demand Side Response, electricity demand, households, Latent Class Model, multipart tariffs

1. Introduction

Poland's power grid is under strain during peak hours, especially during summer heat waves. Peak loads occur between 1 p.m. and 3 p.m. in summer, as well as all year round in the evenings after the end of the business day. Consequently, the Transmission System Operator is searching for methods to mitigate the pressure put on electricity infrastructure. Its primary tool is the utilization of Demand Side Resources which include improving energy efficiency, use of smart grids in the distribution of renewable energy, and a demand response mechanism. Prices during the off peak and peak period should be set equal to the marginal cost of energy and capacity to maximize the social surplus [5]. This research was carried out to provide an insight into consumers respond to price incentives that correspond to this problem.

Energy demand management, also known as demand side management, consists in the modification of consumer demand for electricity through various methods such as financial incentives and behavioral change through education. Ordinarily, the goal of the DSM is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times such as nighttime and weekends. Peak demand management does not necessarily decrease total energy consumption, but could be expected to reduce the need for investments in distribution networks or power plants thanks to a more balance pattern of consumption throughout the day. Demand Side Response is a change in consumer behavior as a response to incentives provided by electricity distributors, for example tariff programs.

Automated Metering Infrastructure, often referred to as 'smart grid', fundamentally changes the concept of a traditional energy system by enabling two-directional communication with customers through the grid. In particular, it can be used for prompt adjustments of household tariffs, either Time of Use or Dynamic tariffs. This way a price signal can reflect a relative scarcity of resources in the power grid more accurately [3]. There are many ways of implementing time-varying pricing in household tariffs. Time-of-use rates with different per-unit prices for usage during different time blocks, critical-peak pricing rates with high per-unit rates during high consumption periods and real-time pricing rates that vary continuously over time so as to reflect the current wholesale price [5]. The AMI provides a detailed consumption profiles of clients, which is essential for rational decision-making. The AMI also allows for a better monitoring of consumption by households, thanks to providing updated readings of the meter every 15 minutes. Smart grids also allow to eliminate inaccurate meter readings.

2. Problem identification and basic principle

The main objective of this study is to investigate if consumers shift electricity consumption between time periods, particularly from weekdays to weekends thanks to the use of multipart tariffs. Tested hypothesizes are:

1. Mean relation between electricity consumption during weekends and weekdays in group EPC1 is the same as in the control group,

2. Mean relation between electricity consumption in weekend day and weekdays in groups EPC2 is the same as in the control group,

3. Mean relation between electricity consumption in weekend day and weekdays in groups EPC3 is the same as in the control group.

This paper also examined household groups in categories with differing abilities to shift electricity consumption. Another verified hypothesize is:

4. It is possible to categorize households in respect of changes in electricity consumption behavior (usage on weekdays and weekends).

3. Methodology

This research is based on existing study "A Test Conducted in Kalisz". The most important data was electric meter measurements. Energa provided data from meters on daily consumption for each of the surveyed households from January 2013 to June 2014 (there were 1,285 households in the research group, and 1,236 in the control group). This was accompanied by socio-economic data collected by a polling agency, on a sample of more than 1700 households [2]. Participants in the test were recruited from a subpopulation of households that had been using the G11 tariff, a standard flat tariff for households, used by more than 80% households in Poland. Prospective participants did not have a choice – each of them received an offer to participate in a specific research group defined by a type of tariff that was proposed. Upon being eligible and interested, a household concluded an agreement with PBS to respect various laws, including privacy of data [4].

There were three research groups – three with TOU tariffs (EPC1, EPC2, EPC3).

EPC1 – designed by the distribution company, it retains the same profile across all seasons, is characterized by two different rates for different periods for peak and off-peak hours, with moderately increased fees (by 80% above flat tariff G11) that cover early afternoon and evening peaks, was offered to 428 households.

EPC2 – designed by the Transmission System Operator , it has a single rate with increased fees (by 120%), however timing of this zone moves along a time axis from a season to a season in order to follow critical peak loads in the energy system (in summers it is early afternoon, in other seasons it is evening), was offered to 432 households.

EPC3 – designed by the Transmission System Operator, key features are the same as in EPC2 but there is an additional 2-hour zone with very high fees (180%) that exactly overlaps with the critical peak loads, was offered to 425 households.

The control group was selected using the Propensity Score Matching. The idea of matching estimators is very simple. In cases when the experimental group has a composition different from the population, a valid control group should be constructed to reflect the features of the experimental group rather than the population. One possible way of constructing such a comparison group is to find for each member of the treatment group a best matching member of the sample of untreated individuals. In the case of Kalisz consumer test this model explains the probabilities of participating in the test with characteristics of the households. The propensity scores were obtained as fitted probabilities from this model.

The scheme for weekly household energy consumption was calculated using the following formula:

$$R_{jn} = \frac{\sum_1^2 x_i}{2} : \frac{\sum_1^5 x_i}{5}$$

where x_i stands for daily electricity consumption in a household, j-number of the week, n – number of the household.

Variable „avg" indicates a mean ratio of consumption during weekends and weekdays:

$$avg_n = \frac{\sum_1^{47} R_{jn}}{47}$$

Parametric tests were used to verify hypothesizes 1,2,3. - Student test for independent samples is a method for comparing means, It is useful for verifying null hypothesis that means in control and research groups are equal.

A cluster analysis was based on the Latent Class Model to find out which households shift their electricity usage and in what ways. Latent class analysis consists in classifying similar objects into groups, where the number of groups, as well as their structure are unknown. The phrase "form of a group" refers to the parameters of a given cluster: means, variances, and covariances that also have a geometrical interpretation. Latent class analysis yields a probabilistic clustering approach. Each object is assumed to belong to one class or cluster, it is taken into account that there is uncertainty about an object's class membership [1]. An individual's class-membership probabilities are computed from the estimated model parameters and his observed scores. The LCM was used to verify the hypothesis: „It is possible to categorize households according to changes in electricity consumption behavior (usage on weekdays and weekends)." Latent classes identified in this research correspond to different types of households with respect to answers for pricing incentives. Table 1 (appendix) shows variables constructed for the LCM.

To find out the relationship between the mean weekday consumption and mean weekend day consumption a parametric test of means was applied.

4. Results

Hypothesis 1 about the equality of means in the control group and EPC1 was refuted by the T-student test. The mean relationship between weekend and weekday power usage was higher in the experimental group ($t = 1{,}7423$, $p < 0{,}05$). In EPC1 mean avg (1,165) was significantly higher than in the control group (1,131). Figure 1 presents the comparison of average power usage during weekends and weekdays in EPC1 and the control group.

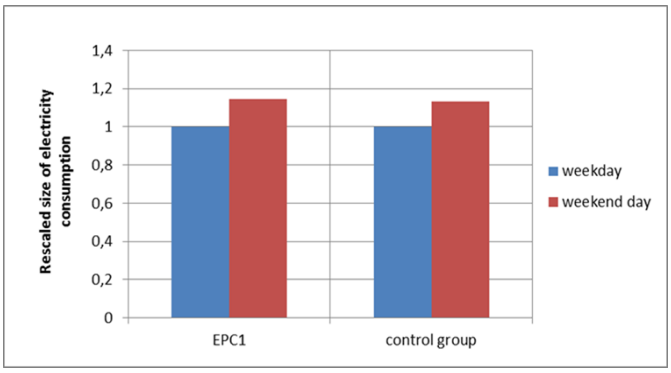

Figure 1. Comparison of mean electricity on weekdays and weekends in the EPC1 and control groups

The result of the T-student test doesn't refute hypothesis 2 about the equality of means in the control group and EPC2. Mean avg in EPC2 and control group doesn't differ significantly ($t = 1{,}056$, $p > 0{,}05$).

The result of the T student test lead to turn down hypothesis 3 about equality of means in control group and EPC3. Mean relationship between usage in weekend day and weekday was higher in research group ($t = 3{,}4212$, $p < 0{,}05$). In EPC3 mean avg (1,152) was significantly higher than in control group (1,109).

Figure 2 shows comparison of mean usage in weekend day and weekday in EPC3 and control group.

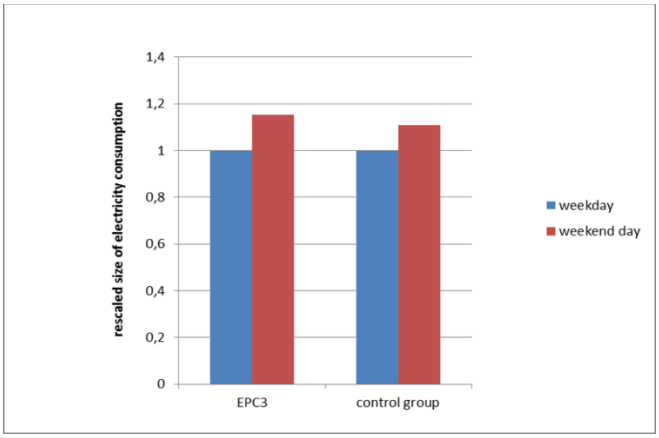

Figure 2. Comparison of mean usage in weekend day and weekday in EPC3 and control group.

This part the paper presents results of the latent class analysis for three experimental programs The dependent variable was red_wee – mean reduction in weekend electricity consumption. Table 2 (appendix) shows information criteria for models. Comparison of information criteria indicated that 3-cluster model fit the data the best.

Latent class model allowed to distinguish three groups of users with different scales of reduction of electricity consumption:

- The first group is the most numerous (55,9% of sample). The mean value of electricity consumption reduction was 694,4211 (kWh) - increase of demand. More than 65% of household premises in this group have a surface of 30-75 m2 and about 63 % of premises in this group are flats. Power bills constituted an insignificant part of household expenses for 40.25% of the group's population. In this class an increase of electricity consumption on weekdays was observed (255 kWh).
- The second cluster encompassed 43,7% of all surveyed households. The mean reduction in electricity consumption in this group amounted to 637,52 kWh. About 40% of households in this group indicated that electricity bills accounted for a small part of total household expenses (less than 0,05 %). It is the group with the lowest average income and the highest education. In this class a decrease of electricity consumption on weekdays was observed (1011,55 kWh).
- The third cluster was the least numerous group of households – 0,42%. Mean electricity consumption reduction during a weekend day reached 637,88 kWh. During weekdays the highest electricity consumption reduction was observed – (mean at 3206,83 kWh). More than 55% of households from this group live in houses. The average number of persons inhabiting a household was the highest in this group. Electricity bills constituted a relatively high portion of total expenses. Analysis of the impact of covariant derivatives on electricity consumption indicated that households which occupy houses or flats of more than 150 m2 had the highest probability of being included to second cluster (56,8%). Also households whose members were more active at night (22.00-7.00) had a high probability of falling into that group.

For covariate red_pow results lead to observations:

- households that reduce electricity consumption by 1-254 kWh were most likely to be found in the second cluster (54 %),
- for households with reduction of 255-508 kWh probability was 72,6 %, for 509-763 kWh - 73,33%, for 764-1017 kWh - 64,81%, • household which reduce electricity consumption the most 1018-1271 KWh have the highest probability of membership to the second cluster (75,43%).

5. Discussion

As a result of applying price incentives, electricity consumption shifted from weekdays to weekends – the structure of weekly usage changed. Figure 3 shows changes in consumption for research groups.

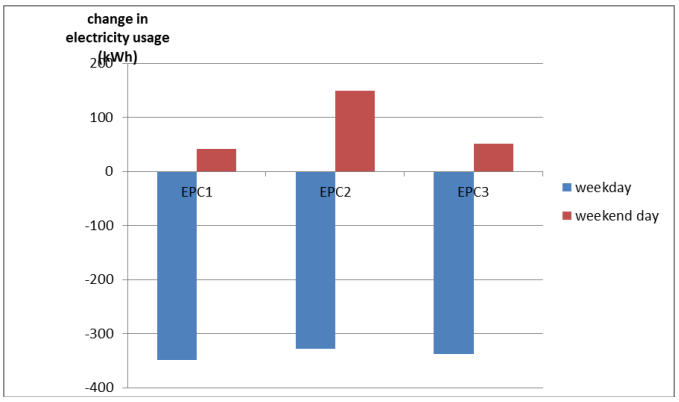

Figure 3. Mean values of electricity consumption changes in research groups

In the EPC1 group the usage shift from weekdays to weekends was equal to 3,4%. This was the households group where rates for electricity usage in particular times of day did not change during the year. The highest unit rate (0,91 PLN per kWh constitutes 180% of the heightened pay rate) was used for the periods between 10 a.m. – 2 p.m. as well as 5 p.m. - 10 p.m. Perhaps households' practices were permanently changed in the price programme through shifting usage to weekend days.

The biggest change in weekly usage structure was observed in the EPC3 group. Households shifted 4,4% of their usage to weekend days. Different pricing for time slots in different seasons was introduced in this price programme. In addition, the pay rate number for electricity rose to four. Presumably the households in the programme had more difficulties in controlling the applied electricity price due to the price list's high level of complexity. The usage shift into weekends, when lower fees for every time of day applied, was found safer.

Results show that households have the possibility of shifting usage reallocation between weekdays. Multipart tariffs demonstrate the potential for reducing load during peak hours is visible in multipart tariffs.

The latent class model revealed three reduction patterns in the analyzed groups. It is accordance with expectations, households' profiles are connected with the price incentives reactions. The most numerous first group is represented by households where the average usage increased during weekend days (by 694 kWh) and during weekdays (by 255,46 kWh), with no energy saving. The total average usage increase in weekend days (1388 kWh) has exceeded the total average change from weekdays (1275 kWh). Households located in blocks of flats or tenement houses with relatively moderate surface are a dominate in the group. According to respondents, electricity bills account for a relatively small portion of spending. It seems that households with a faint possibility of the electricity usage reduction as well as with poor motivation for behavior change, can be found in the class. Households from that segment increased their total consumption as a result of participation in the research. Consumption during peak hours was reduced, but it triggered disproportionately higher increase during other hours as well as in duvet days. Perhaps some households in the segment showed no reaction to price incentives or changes, that were caused by the multipart tariffs' implementation, caused a reverse effect. Namely, no demand shift was observed and an increase in usage was recorded. Studies show that the price flexibility of demand in the long term is higher due to the possibility of replacing flat equipment with more energy efficient models and creating energy saving habits. Hence in a longer time period more pronounced changes in energy demand may be expected.

The second segment is represented by households where electricity usage was reduced both during weekdays (1011 kWh on average) and weekends (637 kWh on average). Relatively many households from the group live in premises with surface area of above 150 square meters. Larger flat surface favor the possibility of reducing the total amount of demand (not only the shift between weekdays effect), which finds confirmation in research reports.

Households recruited for the study conducted in Kalisz could increase the awareness of their behavior connected with electricity consumption and reflect on the behavior. The highest activity time period has not diversified households regarding the likelihood of affiliation to clusters. It is inconsistent with expectations and research results. People expected that the daily usage profile relevantly affects the consumer reaction to the tariff changes. Similarly little differences between segments occur with regard to the income level. In the case of 'r_proc' variable, it was noticed that the biggest slice of the electricity rates in the total spending is present in the third segment. In the case of the group word has it about the biggest impact of the price incentives implementation. The average reduction in a weekend days amounts to 627,88 kWh and the reduction equals 3206,83 in weekdays. It is likely that the households had the increased motivation in order to reduce energy costs. The biggest participation of people with higher education has been observed in the group. It can be enforced by the education level impact on behavior connected with energy saving. The largest number of people being part of a household and relatively high surface area of premises among the class observation suggest that the energy usage before the research period was higher than in other segments. It could be the reason for achieving the largest energy saving effect in the total amounts.

After the research analysis one should remember that participants from the conducted in Kalisz test constitute a specific volunteers group who are more interested in the topic of the energy costs saving. On the other hand, the control group's results for the representative Kalisz residents' sample. It means that for the Test volunteers, the energy costs saving is more important than for the control group or for the total population of households in Poland. The implementation of the OPT-IN option (acceptance for participation in the test) triggered the volunteers recruiting and caused the election of such a research group that is interested more in the new solutions exploitation. Results from the research group should

not be extrapolated to the whole population of households that has been serviced by Energa-Operator S.A. The demand response in the total population of households scale can be estimated as a demand response in the research group cluster multiplied by the analogical group percent in the total population of households. The slice is unknown and it cannot be estimated on the basis of the data received from the test.

The Propensity Score Matching procedure enabled to select the control group that is maximally similar to research group in terms of the daily usage amount. The data casebook concerning the electricity intake at 15 minutes long intervals (it would be 2,3 billion surveys) in the research was not available for use. Access to such exact data would enable better matching of 'twins'.

The conducted in Kalisz test has been the behavioral research by assumption. It would be beneficial to conduct the deepened quality research in order to get to know social reasons and the consumer behavior conditions. Such knowledge would be useful in the planning of educational actions. Owing to the limitation of the thesis volume did not make comparisons that would supply additional information: the t-student's tests conducting for each price programme in subsequent months to catch the changes' dynamics the week electricity usage structure. Time changes are worth checking in the future. The latent classes analysis was conducted for the total usage reduction values. It constitutes the research limitation – in the future it is worth focusing on the relative values' analysis – the reduction against the initial average usage.

6. Conclusions

The new grid elements – smart meters – enabled to conduct a unique research project in Kalisz – to test the experimental price programmes. The aim of the thesis was to check to what extend the multipart tariff implementation, with the increased pay rate during peak hours, caused changes in the week structure of electricity usage.

The research led to the hypotheses verification. It was proved that households testing the EPC1 and the EPC3 have shifted the electricity usage from weekdays to weekend days (respectively 3,4%, 4,4%). The multipart tariffs implementation led to the change of the week electricity usage structure.

Moreover, results suggested that the multipart tariffs implementation for reducing the network load in peak hours is effective. Among households diversity in terms of the price incentives response was observed. The average electricity usage in weekend days (by 694 kWh) and in weekdays (by 255,46 kWh) increased in the majority of households. In the category the effect of the demand time lag – between zones – only occurred. The increase of the total electricity usage was seen in a segment where households using flats in apartment blocks or tenement houses have predominated. Presumably the development type has affected the possibility of minimizing demand. Lower number of people in the household occurred in the segment. It was frequently created by lonely people.

Households that reduced the usage both in weekdays and weekend days were located in other categories created in the research. The electricity usage reduction in weekdays was considerably higher than in weekend days. Hence both the energy saving effect and a demand response occurred.

Further surveys are worth conducting in order to confirm the outcomes stability. Furthermore, it is advisable to care for the sample representativeness towards Polish population. The changes of the week electricity usage structure over the course of time, from the moment of tariffs' implementation, are also worth testing. Due to the action it will be possible to evaluate how fast consumers react to tariffs' shifts and how their behavior changes over the course of time. It would be also valued to take into account additional variables connected with the consumers' lifestyle in the qualitative research.

The survey presented in the thesis has deepened understanding of the multipart tariffs impact on the energy usage in households. Until now the multipart tariffs impact on the electricity usage reallocation during a week was not analyzed. The authorial research was probably the first of that type in Poland. Results may contribute to the achievement of better effects in implementing the demand management mechanisms in Poland. Consequently, it may contribute to the realization of the established energy policy aims. Differences between households should be taken into consideration during the creation of price programmes. Due to such a practice the production of more suitable solutions will be possible in the future.

Abbreviations

AMI - Automated Metering Infrastructure
DSM - Demand Side Management
DSR - Demand Side Response
EPC1 - Experimental Tariff 1
EPC2 - Experimental Tariff 2
EPC3 - Experimental Tariff 3
LCM - Latent Class Model
TOU - Time-Of-Use rates
TSO - Transmission System Operator

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Appendix

Table 1. Variables constructed for Latent Class Model

Variable name	Levels
red_wee weekend day reduction in electricity consumption	Continous variable
red_pow weekday reduction in electricity consumption	Continous variable
income: mean total income in household (PLN)	**1** x < 1500 **2** 1500-1999 **3** 2000-2499 **4** 2500-2999 **5** 3000-3999 **6** x > 4000
Education	**1** primary **2** vocational **3** secondary **4** tertiary
Age	Continuous variable
Status: marital status	**1** married **2** single
N_kids: number of children	**1** 0 **2** 1 **3** x ≥ 2
N_: number of occupants	**1** 1 **2** 2 **3** 3 - 4 **4** x > 4
Bills_per: share of electricity bills in total monthly expanses	**1** < 10% **2** 10 - 15% **3** 15 - 20% **4** > 20%
bills: electricity bills for two months (PLN)	**1** 1 - 100 **2** 100 - 200 **3** 200 - 300 **4** 300 - 500 **5** > 500
building	**1** flat **2** house
Time_ak: time of higher activeness	10:00-12:00 12:00-14:00 14:00-16:00 16:00-18:00 18:00-20:00 20:00-22:00 22:00-7:00 7:00-10:00 Don't know The same all day long

Table 2. Information criteria for Latent Class Model

		LL	BIC(LL)	AIC(LL)	AIC3(LL)	CAIC(LL)
Model 1	1-Cluster	-12594,34	25202,97	25192,68	25194,68	25204,97
Model 2	2-Cluster	-12419,00	24873,74	24848,00	24853,00	24878,74
Model 3	3-Cluster	-12375,84	24808,85	24767,67	24775,67	24816,85
Model 4	4-Cluster	-12375,40	24829,42	24772,80	24783,80	24840,42

Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
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