Demand Side Management in Private Households – Actual Potential, Future Potential, Restrictions

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Abstract. Demand Side Management (DSM) is one way to keep the balance between energy generation and energy consumption and is therefore important in grids with fluctuating renewable energy sources. To explore how typical households with their specific electricity consumptions are able to take part at DSM the DSM potentials were calculated. First the DSM potentials for the single types of load in households that are practical were calculated as actual potential with actual types of appliances. Then they were calculated as future DSM potential with today's high efficient appliances that will have replaced the actual types in households in the future. The future potential considers also expected changes like less distribution of storage heaters and much higher distributions of heat pumps and electric vehicles. Restrictions in case of DSM are considered as well because they reduce the theoretical DSM potential remarkable. Finally the financial benefits through DSM for a typical household with four persons were calculated on base of a tariff with four different prices.

1 Introduction

The increasing energy generation of non controllable renewable energy sources like photovoltaic and wind power makes high demands on the flexibility of the remaining energy producing units and loads. Therefore Demand Side Management (DSM) is becoming more and more important to keep the balance between energy generation and energy consumption. In private households DSM today is only applied for loads like storage heaters or heat pumps.

Part of the E-Energy-Project (http://www.e-energie.info/) "Regenerative Modellregion Harz (RegModHarz)" (https://www.regmodharz.de/) is to find out, how private households in the rural district Harz can take part in DSM. For that it is necessary to have an overview about the specific electrical consumption in households.

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2 Specific Electrical Consumption in Households

The rural district Harz has 237653 inhabitants [1]. For the estimation of the DSM potential the households have been categorized according to the number of persons living in it. Most households are single households (38%), whereas most people live in households with two persons (38%).

The electricity consumption of all households is 331 GWh per year [2]. To determine the specific consumption of electrical energy in households the EnergyAgency.NRW has made a detailed survey [3] with about 28000 households in 2006. All usual loads in households were considered. The results of this survey were used in combination with the above-mentioned types and numbers of households in the rural district Harz to get the distribution of energy consumption on different appliances in households in the rural district Harz (Fig. 1).

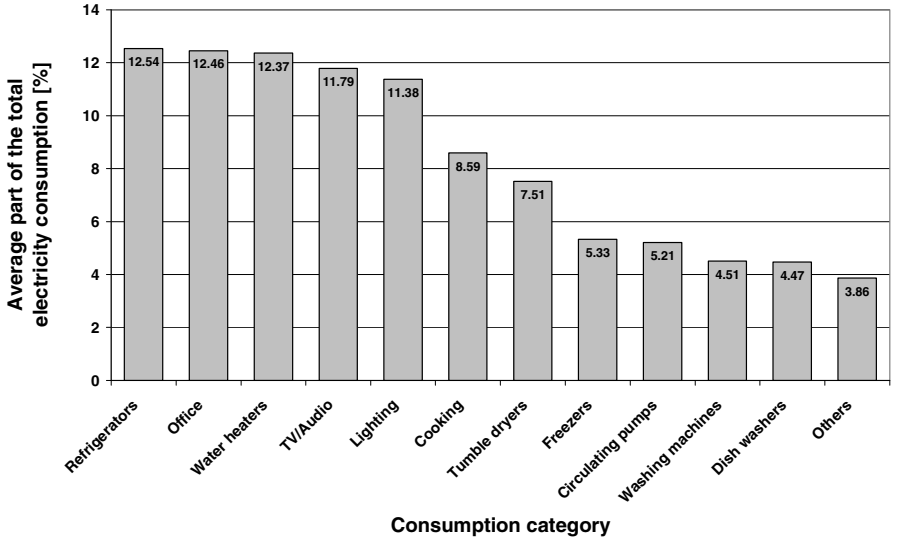

Fig. 1. Distribution of energy consumption on different appliances in households in the rural district Harz

The categories office, TV/audio, lighting, cooking and circulating pumps were not regarded for the calculation of the DSM potential of the rural district Harz because load shifts in that categories are not possible or will cause inadmissible inconveniences to the people in their households. Additionally to the regarded categories of Fig. 1 storage heaters were considered. Therefore the regarded appliances for the actual and future potential are storage heaters, water heaters, refrigerators, freezers, dish washers, washing machines and tumble dryers. The regarded appliances only for the future potential are heat pumps and electric vehicles. Air conditioners were not explored and therefore not regarded for the calculation of the future potential.

3 Actual Potential

The appliances suited for DSM were separated into three different groups. The **first group** includes all appliances whose utilisation depends on the temperature (e.g. electric storage heaters). The electric power consumption of circulating pumps is also depending on the temperature. Nonetheless this appliance was not considered since the usage of circulating pumps for DSM is connected to a perceptible reduction of home comfort. The average electricity consumption of electric storage heaters in Germany is 17.4 MWh per household and year [4]. In the rural district Harz about 2600 households have electric storage heaters which results in a total electricity consumption of 44.53 GWh. It is estimated that this electricity consumption is equal to the DSM potential. Since it was not possible to identify the energy demand for space heating for different sizes of households it was assumed that the electricity consumption of different households is proportional to the energy demand for space heating.

The **second group** includes all appliances whose energy consumption depends on the season and the day of the week. These are washing machines, tumble dryers and dish washers. The average electricity consumption of washing machines was calculated with 0.87 kWh per application. The calculated power consumption is 6.38 kWh per application for tumble dryers and 1.09 kWh per application for dish washers. The power consumption per year depends on the number of uses per year and thereby to the size of the household. The DSM potential of all households considered in Fig. 2 is 10.8 GWh for washing machines, 16.5 GWh for tumble dryers and 11.3 GWh for dish washers.

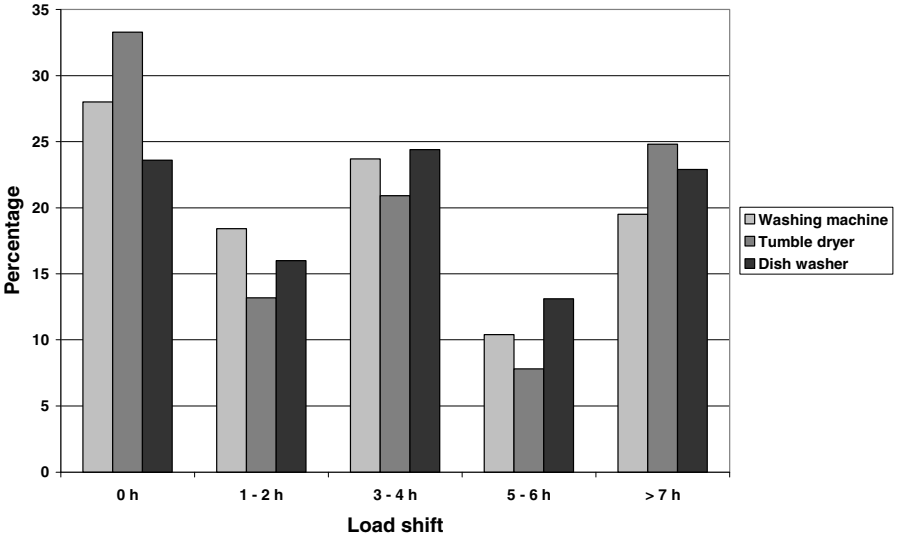

Fig. 2. Maximal load shift per appliances as a result of a household survey in the rural district Harz

Furthermore the information about the maximal load shift of the application is needed. In [5] a maximal load shift of 24 hours is estimated. Fig. 2 shows the results of a household survey in the rural district Harz where questionnaires were send to 2500 households. The results of the 424 returned questionnaires differ remarkably from the 24 hours.

The **third group** includes all appliances which have nearly constant electric power consumption at every day of the year. These are refrigerators, freezers and storage water heaters. The demand of hot water varies irregular from household to household and from day to day. Therefore it was estimated that over all households in the rural district Harz the electric power consumption for water heating is constant at every day of the year. Suited for DSM are only storage water heaters. Usually Storage water heaters consume energy at the hours between 10 p.m. and 6 a.m., when electricity is cheap. Consequently storage water heaters are already used for DSM. It was calculated that about 13000 households have a storage water heater with a DSM potential of 10.3 GWh.

Refrigerators and freezers usually consume electric energy for 20 Minutes at every hour [6]. The starting time of the refrigerator respectively freezer within this hour can be varied and therefore used for DSM. The DSM potential of refrigerators is 41.5 GWh per year and the potential of freezers is 17.7 GWh per year.

Table 1. Electric power consumption of different appliances suited for Demand Side Management in the rural district Harz separated into different sizes of households

Appliance	People in household and their DSM potential [GWh/a]					Overall
	1	2	3	4	5+	
Electric storage heaters	11.5	17.5	9.5	4.7	1.3	44.5
Washing machines	2.3	4.1	2.6	1.4	0.4	10.8
Tumble dryers	1.7	6.2	4.8	2.8	0.9	16.5
Dish washers	1.5	4.6	3.0	1.7	0.5	11.3
Storage water heaters	3.2	4.0	1.9	0.9	0.3	10.3
Refrigerators	15.2	15.7	6.9	2.9	0.7	41.5
Freezers	3.3	7.8	4.0	2.0	0.6	17.7
Overall	38.7	59.8	32.8	16.5	4.7	152.6

Table 1 shows the actual DSM potential in the rural district Harz separated in different sizes of households and different appliances. It must be mentioned that the values in the table also includes households which do not have such an appliance. Therefore storage water heaters have almost the same DSM potential as washing machines, even though storage water heaters consume much more energy per appliance.

4 Future Potential

Two effects have to be considered for the estimation of the future potential. On the one hand the future DSM potential is reduced by the usage of more efficient appliances. On the other hand the future potential increases with new appliances like electric vehicles or with the extension of appliances like tumble dryers, dish washers and especially heat pumps.

The reduction by using more efficient appliances can be estimated by comparing the energy consumption of the appliances in the households in the rural district Harz with the nowadays most efficient appliances. In [7] the most efficient appliances are listed. It is not possible to exactly compare the most efficient appliances with the appliances in the households, since the usage (e.g. washing program) and the size of the appliances is unknown. Therefore the following reduction potentials are rough estimations.

Refrigerators and tumble dryers have the biggest reduction potential each with 72%. Dish washers have a reduction potential of 23.8%, freezers with 21.9% and washing machines have the lowest reduction potential with 5.2%.

Moreover the usage of electric storage heaters is estimated to be zero in the future, since there is an act (Energieeinsparverordnung [8]) that will lead to a continuously reduction of electric storage heaters. The reduction potential of storage water heaters is nearly zero [9].

Thereby the DSM potential of the appliances considered in the actual potential will decrease to 58 GWh respectively 38% of its actual value, if the number of appliances per household remains constant. Fig. 3 shows the difference between the actual energy demand and DSM potential of the appliances and the future potential.

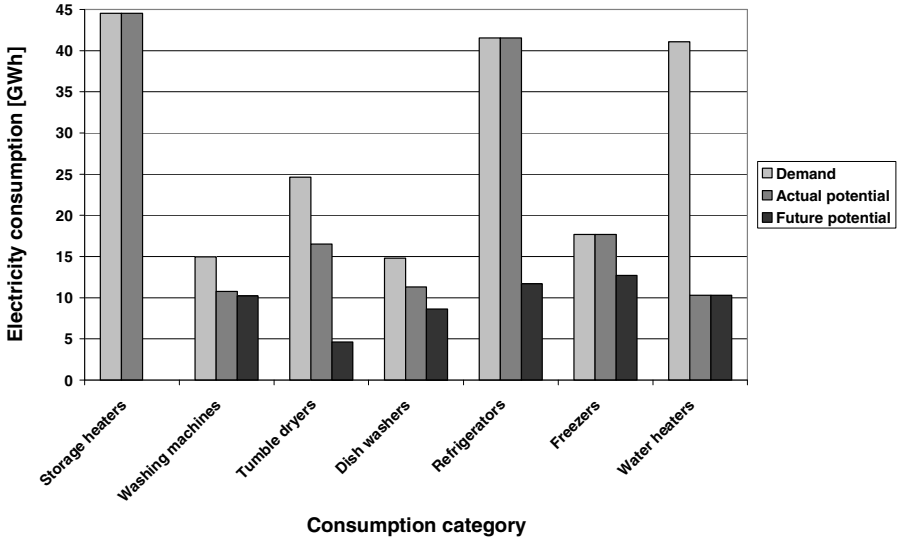

Fig. 3. Actual electricity demand and actual DSM potential as well as future DSM potential of all households in the rural district Harz

In return new appliances like electric vehicles, heat pumps or air conditioners offer a big potential for the future. The average power consumption of an electric vehicle can be estimated to 2.33 MWh per year. If all households in the rural district Harz use an electric vehicle, this would result in an electricity consumption of 280 GWh per year, which is as one appliance 80% bigger than today's DSM potential of all other

appliances. Another interesting application are heat pumps. They can only be used for DSM in combination with a heat store. The average electricity consumption for space heating in Germany is 11.5 MWh per year and household [10]. If this energy is delivered by heat pumps with a coefficient of performance of 3.3, this would result in an electricity consumption of 3.5 MWh per household and year or 422 GWh per year for the rural district Harz.

Consequently new appliances like electric vehicles or heat pumps offer a great potential for DSM, which is much bigger than the actual and especially the future DSM potential of the common appliances.

5 Restrictions

The use of Demand Side Management is often involved with a lot of restrictions. The probably strongest restriction is to change the daily routine in order to achieve a load shifting. Therefore loads like computers, TVs, radios, lamps and stoves were not regarded. But there are also restrictions for other appliances.

When loads like washing machines, tumble dryers and dish washers are used in the night, the generated noise may disturb residents and neighbours. Because of that in apartment buildings the usage of washing machines in the night and partially on Sunday is often prevented by the house rules. Modern appliances are often more quiet than older appliances and the market offers washing machines with features like "Extra quiet" to allow using the appliances in the night.

Another restriction by using washing machines, tumble dryers and dish washers is the household insurance. The household insurance expects an attended use of washing machines, dish washers and tumble dryers. If they were used unattended and a water or fire damage happens the insurance will probably not pay for the damage. To avoid water damages washing machines and dish washers often have a safety system for detecting a leakage. But it is not sure, if the unattended use of an appliance with safety system is handled equally as an attended use of an appliance without safety system by the insurance company.

Not only the washing machine and the tumble dryer have to be suitable for load shifting, also the clothes have to be. If sensible clothes like shirts lay in wet condition some hours in a washing machine or a tumble dryer, then it is most certain that they are no more wrinkle-free. Even when sensible clothes lay in dry condition some hours in a tumble dryer the risk of wrinkle exists.

All the listed restrictions reduce the DSM potential remarkable. They are likely to be the reasons for the small load shifts in Fig. 2. Modern appliances, new insurance conditions and more "wash and wear" textiles could decrease the influence of the restrictions.

If the maximal load shift for refrigerators and freezers is increased by allowing a bigger temperature range, the home comfort could decrease. By maintaining the actual home comfort refrigerators and freezers are only suitable for short time load shifting.

Electric vehicles and heat pumps in combination with heat stores have not only a DSM potential that is much higher than the DSM potential of washing machines, tumble dryers, dish washers, refrigerators and freezers, they also have not the mentioned restrictions. The more the use of an electric vehicle is predictable, the less restrictions DSM has in this case.

6 Financial Benefits through Demand Side Management

DSM will only work, if the monetary incentives are sufficient that the households will change their behaviour. In the following the monetary incentive is calculated for some appliances for a household with four people with the help of the flexible tariff of the Stadtwerke Bielefeld [11]. The tariff EnerBest Strom Smart consists of four different prices in the week between 14.21 Cent/kWh and 25.11 Cent /kWh and two different prices at the weekend (14.21 Cent/kWh and 18.56 Cent/kWh). The maximum monetary incentive for the household can be calculated by multiplying the electric power consumption of the appliance with the difference between the lowest price of the flexible tariff (14.21 Cent/kWh) and the normal tariff of the Stadtwerke Bielefeld (EnerBest Strom 19.10 Cent/kWh) which is 4.89 Cent/kWh. The monetary incentives for a household with four persons for different appliances are listed in Table 2.

Table 2. Monetary incentives for DSM for different appliances of a household with four persons in the rural district Harz

Appliance	Electricity consumption [kWh/a]	Monetary incentive [€/a]
Washing machine	231.3	11.31
Tumble dryer	1062.7	51.96
Dish washer	329.7	16.12
Electric vehicle	2330.0	113.94

The monetary incentives are relatively low, except for the electric vehicle and the tumble dryer. But it can be expected that for people who can afford an electric vehicle the monetary incentive is also too low. Consequently it can be assumed that the monetary incentives by itself is not sufficient to change the behaviour of the people in households.

7 Conclusion and Outlook

The analysis of usual appliances in households shows that storage heaters, water heaters, refrigerators, freezers, dish washers, washing machines and tumble dryers are suited for DSM.

For the determination of the DSM potential in the rural district Harz the appliances were separated into three different groups. The first group includes all appliances whose usage depends on the temperature (storage heaters). This group has a DSM potential of 44.5 GWh per year. The second group includes all appliances whose energy consumption depends on the season and the day of the week (washing machines, tumble dryers and dish washers). This group has a DSM potential of 38.6 GWh per year. The third group includes the appliances whose energy consumption is nearly constant at every day of the year (refrigerators, freezers and water heaters). This group has the biggest DSM potential of 69.5 GWh per year.

Actual the total DSM Potential in the district Harz is 152.6 GWh per year. It can be expected that the DSM potential of the appliances will decrease in the future because of more efficient appliances and a decreasing number of storage heaters. It is estimated, that the future DSM potential in households will go down to 38% of the actual

DSM potential by the usage of the today most efficient appliances, supposing that the number of households and appliances remains constant. But there are new loads that are suited for DSM like heat pumps and especially electric vehicles. The new loads have a DSM potential that is much higher than the actual DSM potential. If all vehicles in the rural district Harz would be replaced by electric vehicles this would result in a DSM potential of 280 GWh per year, which is 180% of the actual DSM potential.

Restrictions like the house rules or household insurances also affect the DSM potential. These restrictions can be faced with improved appliance technologies (e.g. quieter washing machines) and new insurance conditions for appliances with safety systems.

The financial benefits of DSM are rather low for households. For an electric vehicle e.g. the benefit per year is about the costs of one gasoline bill at a gasoline station. The benefits for other appliances like washing machines, tumble dryers and dish washers are even lower. Therefore it can be assumed that the monetary incentives by itself are not high enough to change the behaviour of the households.

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