The Merit Order of Demand Response in Industry

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Abstract:
In previous studies the potential for Demand Response of cross-sectional technologies as well as electricity-intensive processes were analyzed. Two types of load flexibilization were considered: load shedding and load shifting. Furthermore, first calculations of the cost for DR with cross-sectional technologies were conducted, whereas a calculation for the electricity-intensive process is still missing. This paper deals with a new method for determining the opportunity costs of Demand Response across sectors. On the basis of the cost structure of a company as well as the electricity price the opportunity costs for the electricity-intensive industry is calculated. All results are summarized in an overall Merit Order curve for Demand Response.

Keywords: Demand Side Management, Demand Response, flexibilization of load, electricity-intensive processes, cross-sectional technologies, cost analysis; Merit Order

1 Introduction

The structure of the European energy economy is changing. Due to the 20-20-20-goals of the European Union both energy supply and demand need to be restructured. Until 2020 the European Union committed the following targets:

- the reduction of greenhouse gases by 20 % compared to 1990
- the share of renewable energies of total energy consumption shall be 20 %
- an increase of energy efficiency by 20 %

The ambitious objectives of the German "Energiewende" can be achieved by different measures, such as grid expansion or installation of storages. Another possibility is the matching of power demand with supply, which is also referred to as Demand Response (DR) or Demand Side Management (DSM).

Flexibilization of load can be achieved by increasing or respectively decreasing the load of electrical units. Also the generation of companies' own electricity generation plants can be varied. The technical potential of these flexible loads is - compared to other sectors - relatively high. In general, there are two different types of flexible loads. On the one hand there are energy-intensive processes, which can vary their load, on the other hand also cross-sectional technologies like ventilation or refrigeration systems are suitable for offering flexible loads. In Germany the technical potential is about 2,000 MW for energy-intensive processes /FFE-01 14/ and about 800 to 1,400 MW for cross-sectional technologies /DIW-02 13/ (in each case: for an activation of one hour).

The purpose of this paper is to quantify the economic potential of Demand Response for cross-sectional technologies and energy-intensive processes. In this context an analysis of the costs is necessary, which can be divided into initial costs (investments), fixed operating costs and variable costs.

In order to determine the economic potential of Demand Response in this paper first the results of a literature review on Demand Response are illustrated. In the next step the methodology of the calculation is presented. Moreover, the calculated costs for the cross-sectional technologies and energy-intensive processes are constituted. Finally, by matching the costs of both types of flexible loads with the technical potentials, the Merit Order for Demand Response in industry is outlined.

1.1 Definition

Flexibilization of loads

Flexibilization of loads means either load shedding or load shifting compared to the regular operation of a facility. Load shifting only causes a time shift in the production. In other words the lost output can be regained at a later point of time and load shifting has therefore no influence on the amount of production, whereas load shedding induces a loss of production.

Opportunity Costs

Opportunity costs are the value of the next-best alternative that was not chosen because another option was selected. In other words opportunity costs are the costs of a decision for an opportunity of action “x” with the consequence that the opportunity of action “y” cannot be realized /PIN-01 09/.

Merit Order

Merit Order is the sequence of the activation of power plants and is determined by the variable costs of the power generation. First the cheapest power plant is activated in order to satisfy the demand. The last power plant with the highest marginal costs, which was necessary to satisfy the demand, determines the electricity price /FFE-39 10/.

2 Preliminary findings

Within the framework of the Merit Order project – “Energy storage in the year 2030” the Forschungsgesellschaft für Energiewirtschaft is concerned with load flexibilization. In previous studies the FfE could determine the potentials /DIW-02 13/ and the costs of Demand Response /FFE-27 13/ for cross-sectional technologies. Furthermore, the Demand Response potential for electricity-intensive processes in Germany and Austria was analysed and illustrated in regional distribution for both countries.

Until now the costs for cross-sectional technologies and electricity-intensive processes were only analysed for the case of load shifting. In general, for cross-sectional technologies the initial costs are high whereas the activation costs, which are the costs of an actual Demand Response call, are small. Unlike for the electricity-intensive processes, for which the initial costs are negligible while the activation costs are high.

To complete the previous results this paper focuses on the Demand Response potentials and costs of the electricity-intensive processes in case of a total shutdown of the entire production processes. The results of the current paper as well as the preliminary findings are combined in a Merit Order curve for Demand Response.

3 Literature Review

The following paragraph summarizes the related literature dealing with electricity-intensive processes as well as the costs for Demand Response (DR).

The costs can be separated in initial costs (investments), variable costs and fixed costs. The initial costs of DR include investments for installing necessary electric meters, data exchange equipment, a DR implementation strategy and storages for load flexibilization. The investments depend mostly on the status quo of the company itself. Especially in the electricity-intensive industries the investments are often very low (lower than 1 € per kW) as most often real-time metering software is already installed /EWI-09 10/. The investments for smaller companies without an existing building automation can be higher, when an internal load management needs to be installed.

Furthermore, all Demand Response processes need to be able to ramp up and ramp down their load within several minutes depending on the market they are participating in. The qualification of the DR processes for these markets costs ~ 10,000 € /EWI-09 10/.

The fixed costs, which occur regularly and independently of the number of activations, can be separated in information, transaction and control costs. The fixed costs mainly result from the data exchange between the company and the DR centre and are negligible /FFE-27 13/.

The variable costs are only taken into account when an actual Demand Response call takes place. The variable costs refer to the losses which occur due to a reduction of load for industrial processes. These costs only need to be considered when the reduced load cannot be regained later in time (load shedding). These costs can be interpreted as the opportunity costs for Demand Response caused by the lost production during the load reduction. Depending on the industrial branch the costs can be very high. All other processes, which can recuperate the loss of production at a later point of time, face variable costs with a much smaller order of magnitude (load shifting). The shifting capacity is limited by the storage capacity of the process and can be maximised by installing extra storages. But these relatively high investments are usually not taken by companies just in order to offer DR.

Different methods are known for the calculation of the variable costs of DR. In /EWI-09 10/ the variable costs depend only on whether it is possible to make up for the lost load or not. The costs for load shifting are estimated very low whereas load shedding leads to higher costs as the company has to substitute the costs for the lost production. Table 3-1 shows the variable costs for the electricity-intensive branches.

Table 3-1: Variable costs for DR regarding the type of activation /EWI-09 10/

Processes	**Variable costs [€/MWh]**	**Type of flexibilization**
Chloralkali electrolysis	> 100	Load shifting / load shedding
Aluminium electrolysis	500 – 1,500	Load shifting (small) / load shedding
Cement mills	400 – 1,000	Load shifting / load shedding
Wood pulp production	< 10	Load shifting
Electric arc furnace	> 2.000	Load shedding

The chloralkali process is the most flexible process in the electricity-intensive industries, but also difficult to control. Moreover the loss of production of hydrogen needs to be taken into account. The aluminium electrolysis can increase or decrease small amounts of load and can there be used for load shifting. The higher the amount of activated load the higher is the risk of an instable process and therefore higher variable costs. Cement mills mainly produce during night time. This is the reason why shifting the process is possible, but at higher prices for energy. Also additional personal during daytime is required further increasing the costs. Wood pulp production is nearly independent from the paper mills. Electric arc furnaces can be switched off within seconds. The reason for the high variable costs compared to aluminium is the significantly lower electricity-intensity of the whole process and therefore the minor load.

In /ISI-03 09/ the variable costs are calculated regarding the duration of the DR activation. Therefore the call is separated in four sections (Table 3-2). Based on these assumptions, the Merit Order is illustrated in Figure 1.

Table 3-2: Variable Cost for DR regarding the time of activation /ISI-03 09/

Duration of DR activation	**Considered costs**
0 – 100 hours	Electricity purchase costs
100 – 200 hours	Staff costs
200 – 500 hours	Material- and maintenance costs
500 – 1.000 hours	Capital costs for lost production

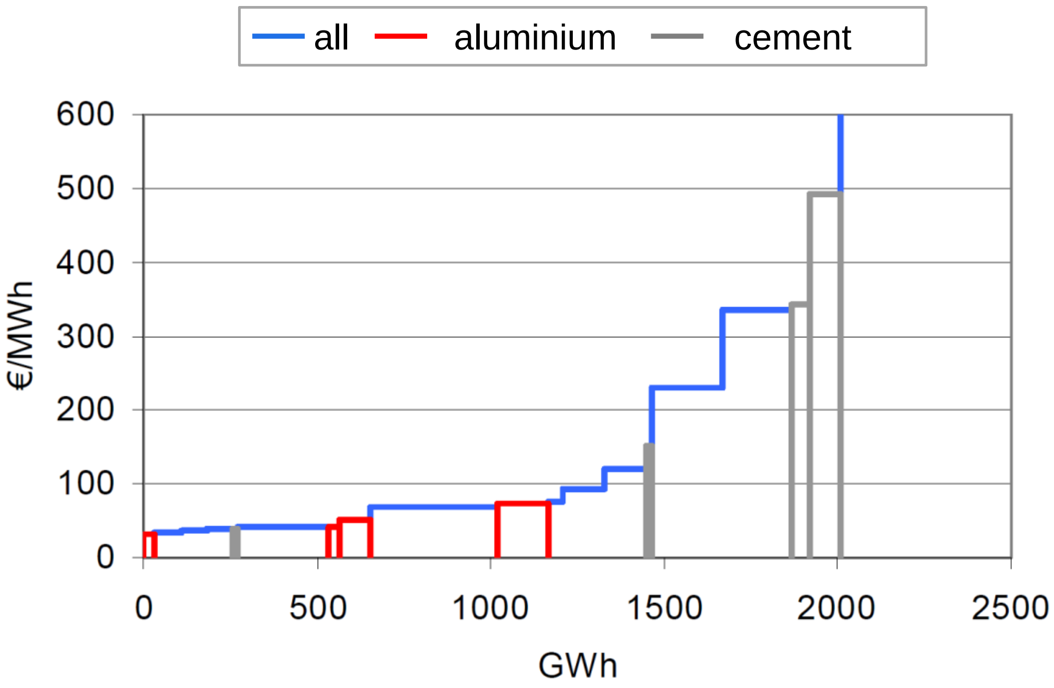

Figure 1: Merit Order for electricity-intensive processes according to Klobasa /ETH-01 07/

The approach considers the fact that short activation periods do not influence the industrial process. Therefore only the electricity purchase costs occur as variable costs. For longer activation periods additionally staff costs and costs for maintenance and material needs to be considered. Longer interruptions lead to production losses and therefore to significantly higher costs.

The previous approaches only considered the flexible processes itself. In some cases it is more economic to shut down the whole company than to produce.

Therefore another publication was reviewed which calculated the value of lost load in case of a total blackout /PRA-01 13/. It is assumed that during an interruption of the electricity supply no added value is possible in the company. Therefore, the opportunity costs for an interruption can be seen as the gross value added during that time.

The ratio of the gross value added *GVA* to the annual electricity consumption *E* illustrates the interruption costs of the not-consumed energy for a specific branch *b*. This is similar to the value of lost load for one branch (formula 1):

$$VOLL_b = \frac{GVA_b}{E_{b,el}} \tag{1}$$

VOLL – value of lost load
b - branch
GVA – gross value added
E – annual electricity consumption
el - electricity

The approach calculated the *VOLL* for all 51 branches in Germany. Table 3-3 only shows the branches which are important for the electricity-intensive industries.

Table 3-3: Value of lost load for the electricity-intensive branches in 2007 /PRA-01 13/

Branches	Value of lost load [€/MWh]
Manufacture of chemicals and chemical products	870
Manufacture of basic iron, steel and non ferrous metals	620
Other mining and quarrying	1,750
Manufacture of paper and paper products	470

The costs were only calculated for the branches in total. Thus, the costs for the eletricity intensive-processes itself can not be detected accurately. The production of alumnium and steel for example is summarized in the branch "Manufacturing of basic iron, steel and non ferrous metals".

Overall the three approaches differ in their results (Table 3-4). The first difference is the data basis used. While in /EWI-09 10/ the information is coming from interviews, statistics and information of the different organisations, Praktiknjo is using only statistical data from governmental agencies. Moreover, Klobasa calculated the costs for a total shutdown of all of the companies of one branch, whereas Borggrefe only considers the electricity-intensive processes itself. Klobasa also uses the information from interviews of companies or statistical data of different organisations, but the methods of calculation differs from the one of Borggrefe. He calculated the costs in dependence of the duration of the call whereas Borggrefe only differentiates between load shedding and load shifting. Furthermore, it is not possible to determine the calculation procedures of the variable costs conducted in these publications.

Table 3-4: Comparison of the flexible loads of the three different approaches /EWI-09 10/, /ISI-03 09/, /PRA-01 13/

Processes	Variable costs [€/MWh]		
	/EWI-09 10/	/ISI-03 09/	/PRA-01 13/
Chloralkali electrolysis	> 100	-	870
Aluminium electrolysis	500 – 1,500	75	620
Electric arc furnace	> 2,000	-	
Wood pulp production	< 10	-	470
Cement mills	400 – 1,000	490	1,750

4 Methodology

The Merit Order curve consists of two parameters: specific costs (costs for the activation and opportunity costs in €/MWh) and the amount of flexible loads per technology and per type of load flexibilization. In the following chapter the methodology to determine these parameters are shown.

4.1 Variable costs of electricity-intensive processes (load shifting)

The technical potential of load shifting in electricity-intensive processes has already been determined in /FFE-01 14/. To integrate this part in the Merit Order curve, the costs for load shifting in these branches were gathered. Therefore interviews with companies, which already brought their flexible loads to the market, were conducted. About half of the interviewed enterprises have electricity-intensive processes. The activation of these processes is realized manually. Most of them get a phone call with the instruction e.g. to reduce the load or shut down the whole unit. In order to restart an electricity-intensive process an employee is required on-site. Additionally costs occur due to a more inefficient production. If a process operates most of the time in partial load, the losses are proportionally higher than in a full load operation mode.

By taking into account the magnitude of flexible loads in case of load shifting the variable costs in €/MWh can be determined.

4.2 Variable costs of electricity-intensive processes (load shedding)

The variable costs clearly increase in case of load shedding. Figure 2 shows the general structure of costs and earnings in companies.

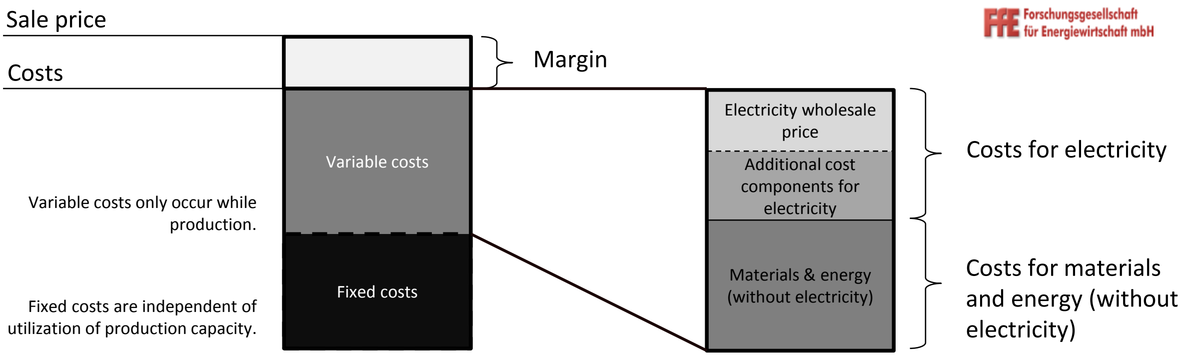

Figure 2: Structure of costs and earnings in the manufacturing industry

The sale price equals fixed and variable costs as well as the profit (see also formula (2)).

$$SP = FC + VC + M \tag{2}$$

SP – sale price
FC – fixed costs
VC – variable costs
M – margin

$$TC = FC + VC \tag{3}$$

TC – total costs

While the fixed costs are independent of production, the variable costs include the costs occurring during the production process. Besides electricity, materials and energy (without electricity) are the significant factors (formula (4)). The price for electricity includes the electricity wholesale price and levies and taxes as well as use-of-system charge.

$$VC = VC_{el} + VC_{ma,e} = VC_{el,eex} + VC_{el,a} + VC_{ma,e} \quad (4)$$

el – electricity
ma – materials
e – energy (without electricity)
eex – wholesale electricity market
a – additional cost components for electricity

Usually companies with electricity-intensive processes purchase their electricity from the wholesale market or even directly from the spot market, e.g. the European Energy Exchange (EEX, see also Figure 3). The different types of costs have to be paid to the EEX, the state and the grid operator.

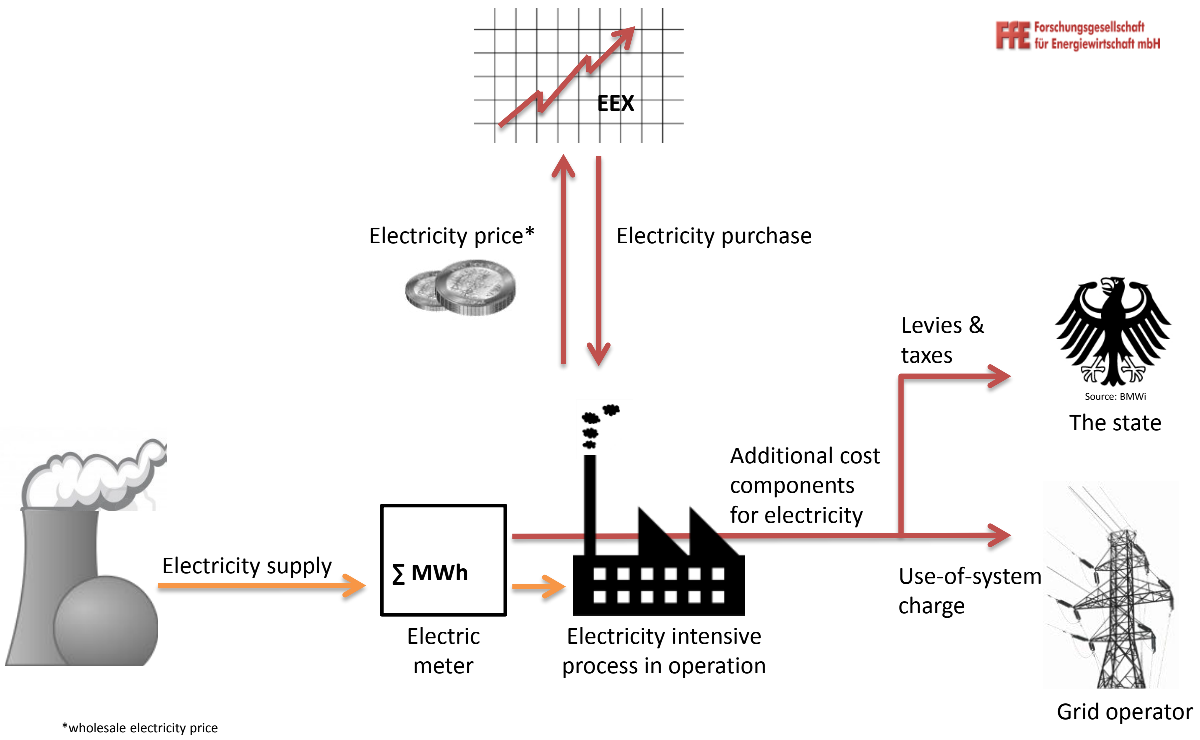

Figure 3: Electricity purchase and occurring costs

In case of load shedding in terms of load reduction or shutdown of a unit the enterprise still has to pay the already purchased electricity by contract. If the electricity is not required by the company itself, it will be transmitted to the grid. Hence, the enterprise has to pay the wholesale electricity price (see also Figure 4). Additional cost components must only be paid for the consumed electricity (measured by the electric meter). Due to this fact, the earnings for an activation of flexible loads have to be at least the sum of the electricity price (wholesale electricity price) and the profit contribution.

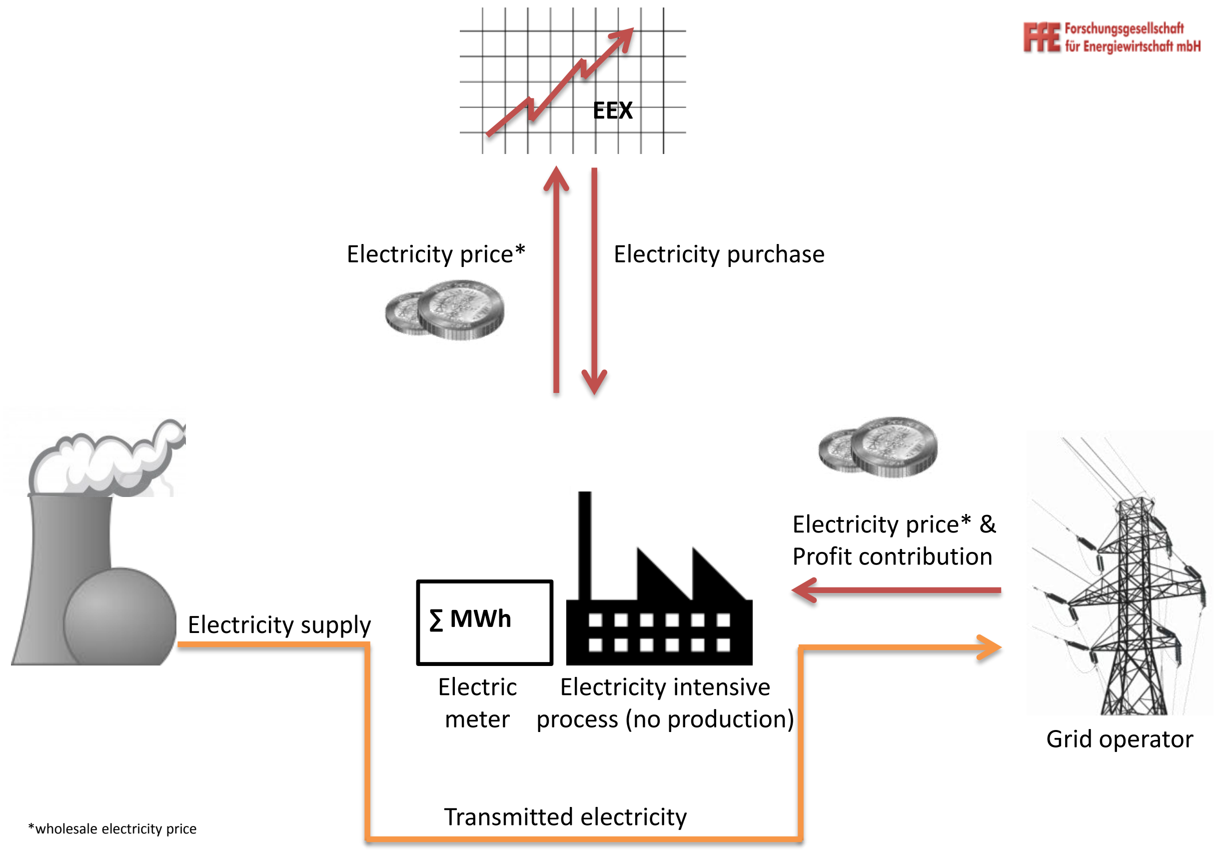

Figure 4: Electricity purchase and occurring costs in case of a Demand Response activation

Load shedding leads to loss of production. For economically feasible load shedding the revenues being generated have to be as high as the opportunity costs. The opportunity costs include the profit contribution and the wholesale electricity price or respectively wholesale market price minus variable costs plus wholesale electricity price (Figure 5, formula (6)).

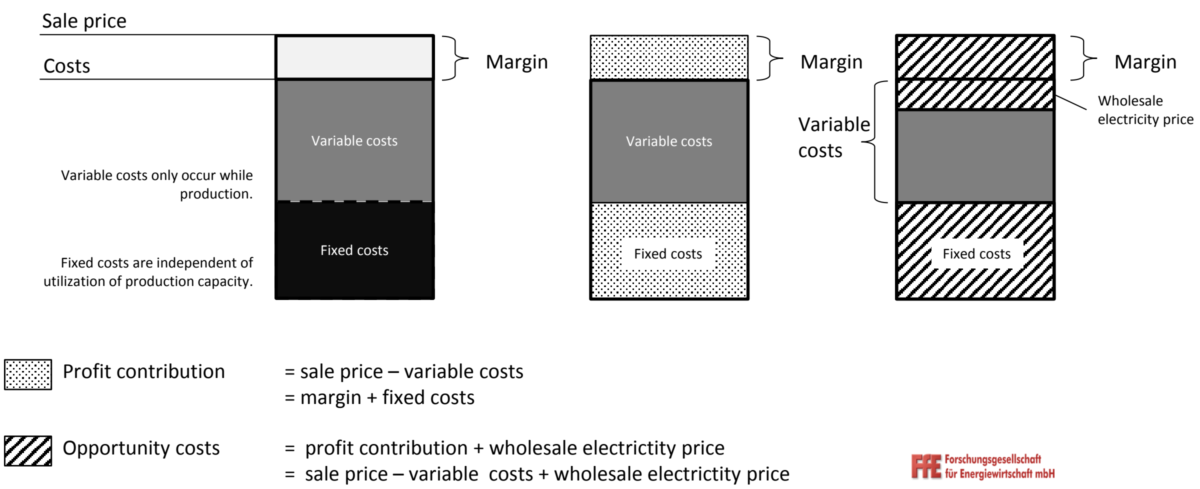

Figure 5: Structure of costs, earnings and opportunity costs

$$PC = SP - VC \tag{5}$$

PC – profit contribution

$$OC = PC + VC_{el,eex} = SP - VC + VC_{el,eex} \tag{6}$$

OC – opportunity costs

The shares of costs are defined in formula (7), (8) and (9).

$$vc_{el} = \frac{VC_{el}}{TC} \tag{7}$$

vc – share of costs

$$vc_{ma,e} = \frac{VC_{ma,e}}{TC} \tag{8}$$

$$fc = \frac{FC}{TC} \tag{9}$$

fc – share of costs

$$vc_{el} + vc_{ma,e} + fc = 100\ \% \tag{10}$$

The share of the margin on the sale price is clarified in formula (11).

$$r = \frac{M}{SP} \tag{11}$$

r – percentage of margin

Based on the above mentioned formulas the opportunity costs are a result of electricity price and profit:

$$OC = \frac{(1 + r) - vc_{ma,e} - vc_{el} * (\frac{(VC_{el,eex} + VC_{el,a}) - VC_{el,eex}}{(VC_{el,eex} + VC_{el,a})})}{\frac{vc_{el}}{(VC_{el,eex} + VC_{el,a})}} \tag{12}$$

The formula shows that in case of given shares of costs the opportunity costs only depend on the wholesale electricity market price, the costs for duties, levies and taxes and the margin.

A detailed description of the cost structure of selected electricity-intensive processes in 2005 is shown in Figure 6.

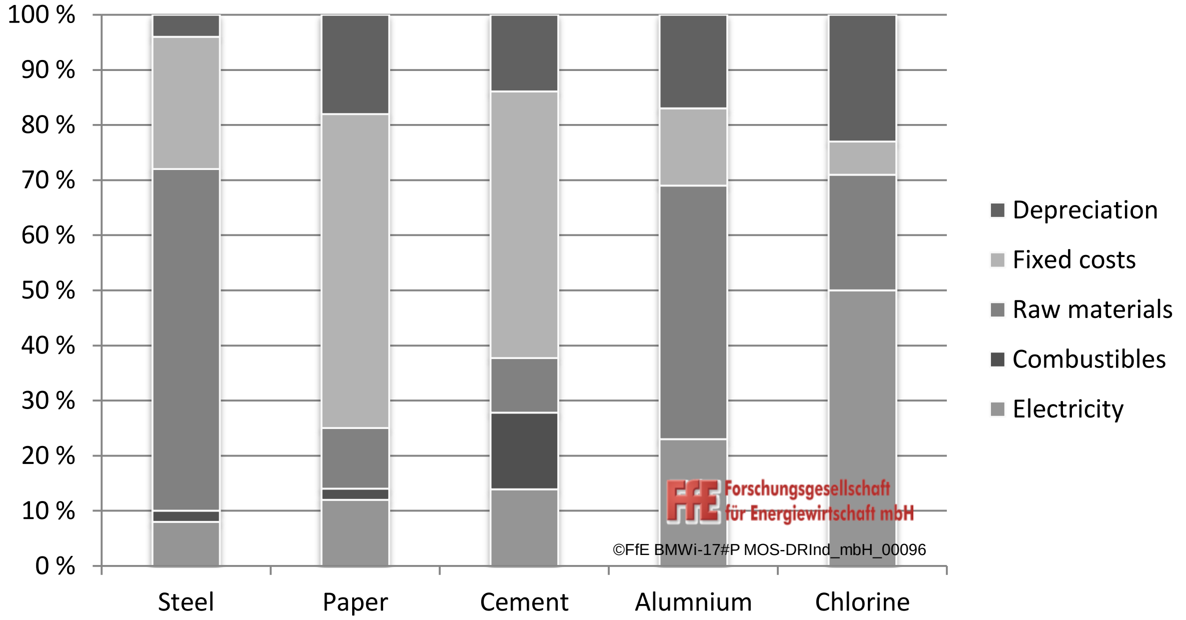

Figure 6: Distribution of costs according to Reinaud (2005) and Klobasa (2002) /IEA-01 04, ETH-01 07/

In the first step, the cost structures of Reinaud and Klobasa were used to calculate the opportunity costs. To utilize recent data, the cost structure of different branches was determined based on structural data of the manufacturing industry from Destatis /DESTATIS-03 14/.

4.3 Potential of electricity-intensive processes in case of lost load

After calculating the opportunity costs of load shedding of electricity-intensive processes their potential is determined. In case of load shedding the potential of flexible loads is obvious higher than in case of load shifting as the whole production process is shut down.

To quantify the magnitude of the flexible load for load shedding the energy consumption according to Destatis /DESTATIS-03 14/ was deployed. The mean load of these electricity-intensive processes can be calculated by the division of energy consumption and mean operating hours (according to /FFE-01 14/).

$$P_{b,el} = \frac{E_{b,el}}{OH_b} \tag{13}$$

E – annual energy consumption
P – mean load
OH – mean operating hours per annum
b – branch
el - electrical

The determined potential includes the potential of load shedding and load shifting. Therefore the already quantified potential of load shifting has to be subtracted from the total potential.

5 Results

The Merit Order curve is compiled based on the results for variable costs and flexible loads of electricity-intensive processes and cross-sectional technologies.

5.1 Variable costs of electricity-intensive processes and cross-sectional technologies (load shifting)

Based on the interviews with Demand Response participants an estimation of the effort to shift electricity-intensive processes was made. About one to two hours per activation were assumed. The efficiency losses in case of partial load are calculated with 5 % in comparison to the full load operational mode. By taking into account the flexible load of these processes the variable costs add up to less than 10 €/MWh.

The variable costs of cross-sectional technologies are also very low, in /FFE-27 13/ the variable costs were declared with 8 € per activation. Assuming that the magnitude of the flexible load is averaged to about 500 kW per company and the activation lasts about 1 h, the variable costs add up to 16 €/MWh.

5.2 Variable costs of electricity-intensive processes (load shedding)

The matrix in Figure 7 shows the opportunity costs for load shedding with a margin of 20 % and a wholesale electricity market price of 45 €/MWh. If the share of electricity costs as well as material and energy costs (without electricity) are available, the opportunity costs can be estimated. The electricity price for clients including taxes, duties and levies is dependent on the share of electricity of the total costs.

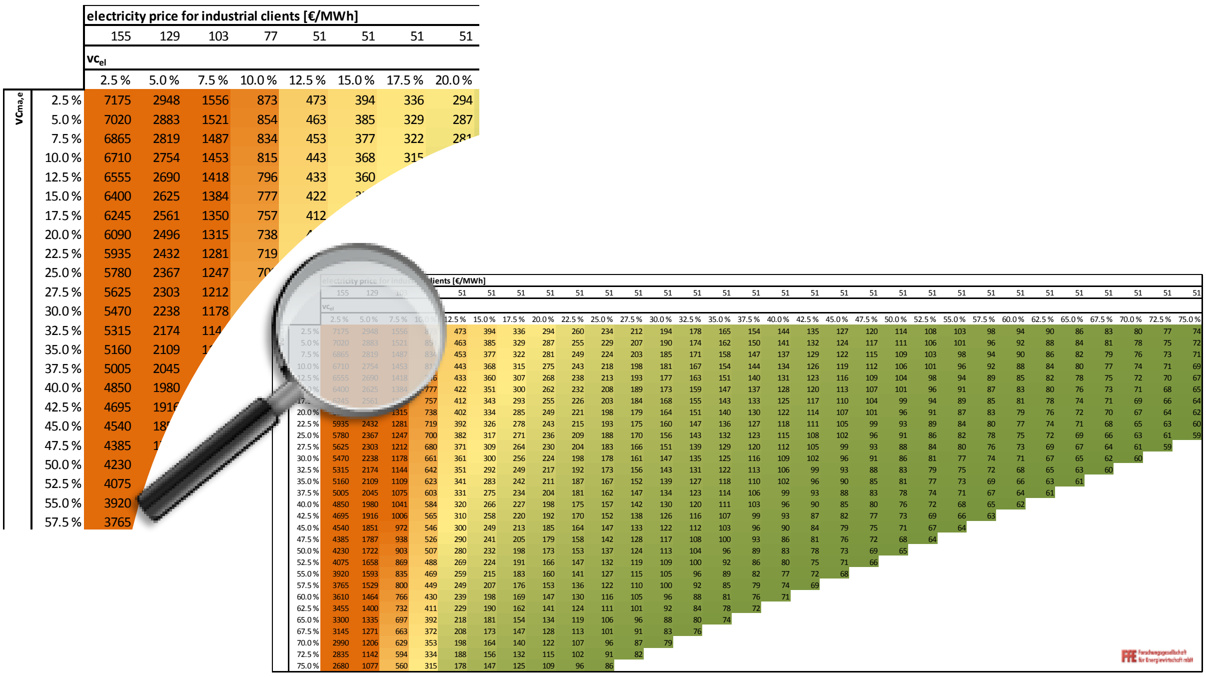

Figure 7: Opportunity costs dependent on electricity price and percentage of electricity costs and material and energy (without electricity) costs

Based on the cost structure of Reinaud and Klobasa the opportunity costs for the electricity-intensive processes were calculated. Figure 8 demonstrates the costs for the selected branches respectively processes. Whereas the opportunity costs of the chlorine production are about 100 €/MWh and relatively low, the costs of the paper or steel production are about 350 to 400 €/MWh. For comparison: flexible loads according to the German ordinance for interruptible loads (AbLaV, /BUN-02 12/) get in case of an activation an average price at about 400 €/MWh (this price is pointed out as dark line in Figure 8).

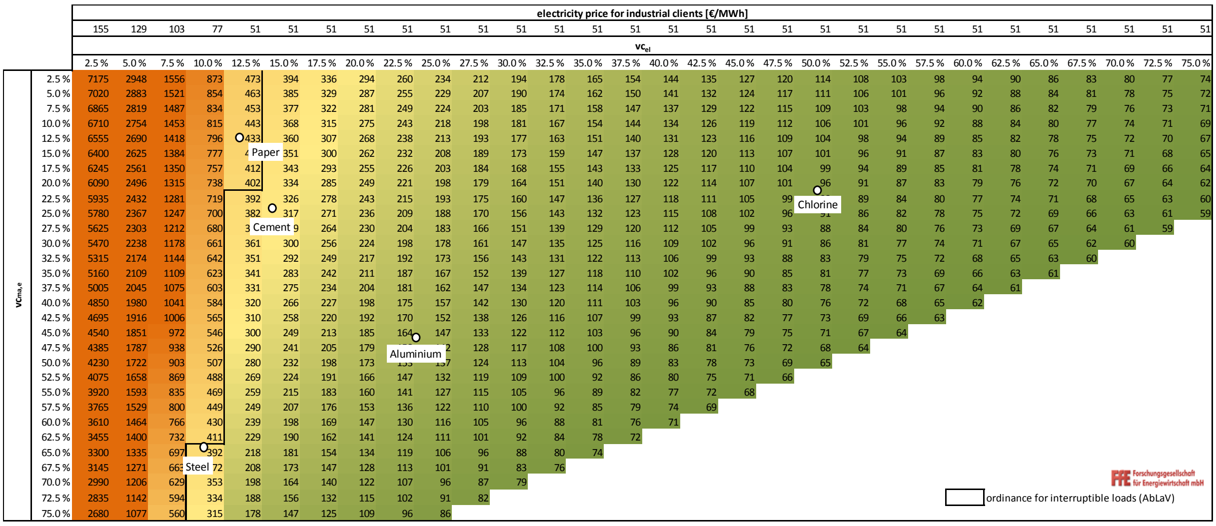

Figure 8: Opportunity costs of selected electricity-intensive processes

An update of these costs was realized with data from destatis. However, due to the missing subdivision of branches the calculated opportunity costs were very high. For example, the manufacturing of primary and secondary aluminium is aggregated, which leads to a lower percentage of the electricity costs compared to the manufacturing of only primary aluminium.

5.3 Potential of electricity-intensive processes in case of lost load

The electricity consumption in Table 5 includes the total electricity consumption for the above mentioned production processes. In case of the manufacturing of steel the electricity consumption for electric arc furnaces is declared.

The potential for flexible loads is divided into two groups. The load shifting potential can be easily realized as the related costs are relatively low. The load shedding potential is clearly higher but the opportunity costs influence the profitability of a participation in Demand Response programs significantly.

Table 5: Potential of electricity-intensive processes (load shedding) /DESTATIS-03 14, EEFA-01 05, ETH-01 07, FFE-01 14/

	Paper	Chlorine	Cement	Alumnium	Steel	All branches
Electricity consumption (MWh/a)	20,397,500	7,609,638	5,067,822	6,865,938	6,797,977	239,921,111
Mean operating hours (h/a)	7,500	7,700	5,500	6,100	6,100	6,721
Mean load (MW)	2,720	988	921	1,126	1,114	35,695
Flex. load (load shifting, MW)	313	593	152	267	718	1.400*
Flex. load (load shedding, MW)	2,407	395	769	859	397	27,426

* Cross sectional technologies

All other branches could also offer load shedding. Considering all above published potentials for load shifting and load shedding, the residual flexible load for load shedding is about 27 GW. But calculating the opportunity costs with the given statistical data for the cost structure in the remaining industry, the opportunity costs would exceed significantly 10,000 €/MWh and load shedding would not be a realistic option.

5.4 Merit Order of Demand Response in industry

The Merit Order of Demand Response in industry is shown in Figure 9. It includes load shifting and load shedding (loss of production) for a time period of one hour. About 3,500 MW are available for load shifting with very low (< 20 €/MWh) marginal costs. The potential of load shedding with electricity-intensive processes is about 4,800 MW, but the marginal costs are higher (100 to 500 €/MWh). While the opportunity costs of chlorine production are relatively low, the costs of the paper production are about 500 €/MWh.

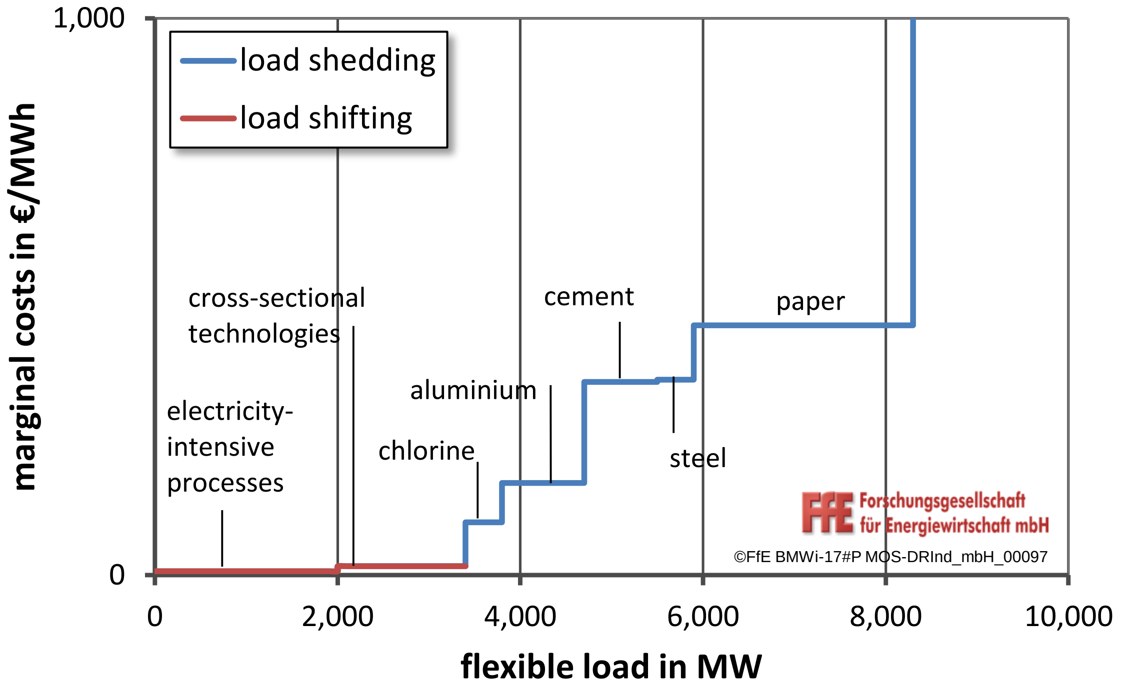

Figure 9: Merit Order of Demand Response in Industry

6 Conclusion

In the first step, a methodology to calculate the opportunity costs was developed. Furthermore the variable costs for load shifting of electricity-intensive processes and cross-sectional technologies could be quantified. Additionally to these costs the technical potential for load shedding was determined. Based on these results the Merit Order for Demand Response in industry was built.

It has been demonstrated, that the marginal costs of load shifiting are very low compared to the marginal costs of load shedding as a loss of production leads to higher costs.

Compared to existing markets for flexibilization as the load frequency control market with about 6 GW, industrial units and processes offer relatively large flexible loads and in case of load shifting their marginal costs are very low. A limiting factor for electricity-intensive processes is a loss of production as a consequence of a flexible operation mode in order to offer Demand Response. In this case, the marginal costs respectively the opportunity costs increase substantially. As a consequence these processes are no longer price-competitive in comparison to other technologies. The benefits of cross-sectional technologies are the almost constant availability and the possibility of a frequent activation.

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