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Demand response technologies as optimal storage options in 2030

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Abstract

The project Merit-Order of Storages (MOS) 2030 discusses the needs of additional storage technologies for the year 2030 from different angles. Not only the systemic point of view is regarded and discussed, but also the potential earnings of different technologies considering fees and taxes for storing energy.

A linear optimization model is deployed to simulate the implementation and usage of different elements of the power system for the year 2030. In the same step, the model optimizes the installation of additional flexibility options such as conventional technologies as well as functional storage systems as demand side management for example. To outline the difference between a systemic point of view and a stakeholder element focused perspective, three different approaches of additional installation and usage of flexibility options are discussed.

In a first step, the systemic optimum of the enhancement and operation of flexibility options is calculated regarding the overall economic costs. The second run describes the usage of the in step 1 defined elements under the context of taxes and fees the different units have to take into account. A third and last run computes anew the additional installation and usage of storage technologies, this time against the background of fees and taxes.

The different simulation runs show that the installed technologies, their capacities and their usage (cf. Figure 1) diverge for a systemic point of view and a stakeholder optimum.

While already existing storage systems like pump-storage-systems are used less frequently when fees and taxes increase, functional storage options as DSM in industrial processes and cross-sectional technologies as well as flexible usage of domestic and public heat generation become more and more attractive. Additionally, DSM in industry is the major option for all three optimization runs as its potential is fully developed for the systemic optimization as well as the stakeholder optimal solution.

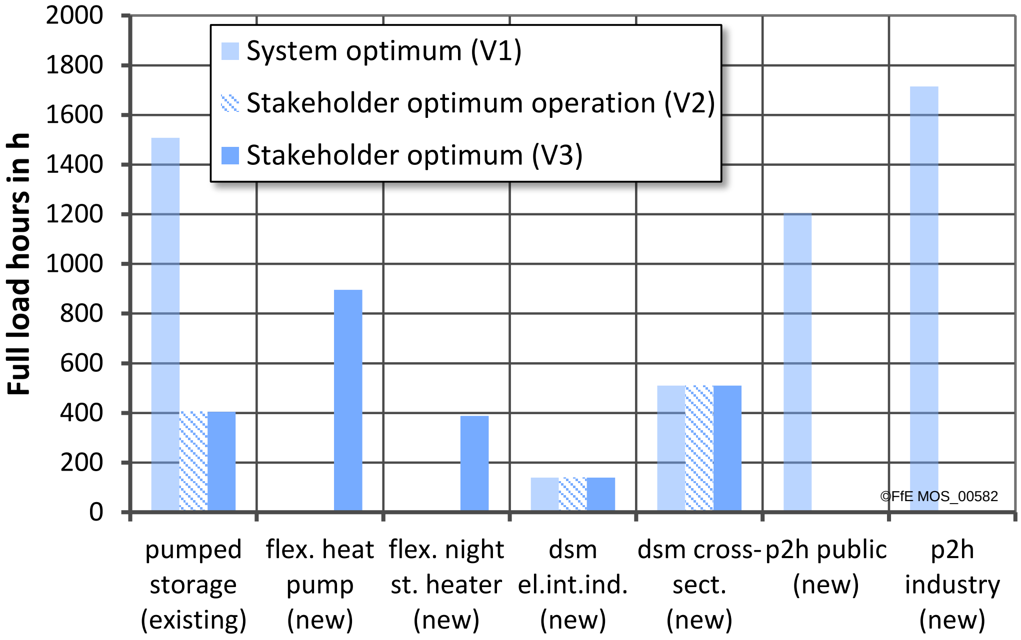

Figure 1: Full load hours of existing and newly installed storage technologies

The overall conclusion is that the actual regulation framework doesn´t lead to a cost effective implementation and operation of flexibility options in the future energy system.

Background

The energy transition of the German energy system leads to various challenges that need to be faced. Amongst those, one of the most discussed is the need of new forms of flexibility to substitute the flexibility afore supplied by conventional power plants and to provide temporal and regional decoupling of energy production and consumption. The storage sector has become a strong center of research as it is considered the most promising source of flexibility for energy systems. But not only conventional storage units do have the ability to shift consumption and production. Adaptable demand and the electrification of other sectors have the potential to integrate surplus generation and to provide supplementary flexibility to the power system. When used as load shifting options, demand response technologies are considered as functional storage units. From a systemic point of view, storage systems can be described as elements in the power system, that allow to augment the load in times of high production and low demand and to raise the production in times of high demand and missing production. Functional storages like demand response even have the advantage compared to conventional storage units that it does not need to be charged before discharging.

Having no losses of energy conversion, most of the functional storages seem to be more adapted for load shifting because no energy is lost during the storage process as there is no such classical storage process. The main deficit of demand response technologies is that temporal restrictions due to coupled processes do not allow an unrestricted usage of their potentials, what needs to be taken into account. Thus, all storage technologies have advantages and disadvantages, which affect their contribution to the power system. To be able to compare the influence on the power

system and the economy of different technologies, a fundamental energy model is used to calculate the operation and the additional installation of storage technologies for the future.
In a first step the fundamental approach allows to identify the optimal solution from a systemic point of view regarding necessary further enhancement of storage technologies. While this solution stands for the systemic optimum that minimizes the overall economic costs, it does not represent the optimum from a stakeholder's point of view. Storage units have to pay different fees and taxes for electricity they lead into their storage systems, such as network charges, which are not considered when the systemic optimum is calculated. From a stakeholder's perspective, these fees have to be taken into account when the profitability is calculated. The systemic optimum and the stakeholder's optimum can be compared and thus lead to a conclusion about the need of political measures to guide the system towards the systemic optimum.

Approach

Within the project Merit Order of Storages (MOS) 2030, demand response as a functional storage is considered a storage technology comparable to a conventional storage technology like pumped storages. The different technologies are analyzed regarding their impact on the power system in the year 2030. They are compared based on their recent and future techno-economical potentials and these parameters are used as input for the fundamental energy system modeling tool ISAaR, which allows determining the impact of different storage technologies on the power system. It is a linear optimization model, which calculates the operation of the main elements in an energy system on an hourly basis by minimizing the overall costs. To calculate benefits and losses of storage technologies, the shadow price of the optimization for power generation is used, representing the spot prices. The approach shown in **Figure 2** was developed in [1] and [2] uses three different simulation runs to determine system and stakeholder optimum expansion and operation. In this paper, a scenario is presented where exports in Europe are not fixed between the different optimization runs, which leads to a more flexible behavior of storages.

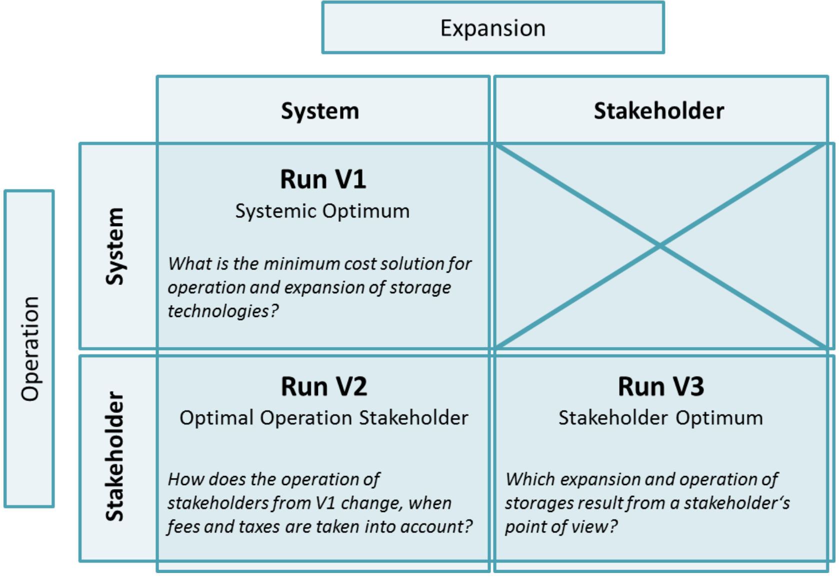

Figure 2: Overview and main issues of the simulation runs

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[1] PhD-thesis Christoph Pellinger: "Mehrwert funktionaler Speicher aus System- und Akteurssicht", FfE, Munich 2016 (unpublished)

[2] C. Pellinger, T. Schmid, et al.: Merit order of storages 2030, FfE e.V. Munich, 2016

The run V1 represents the systemic optimum for enhancement and operation of storage technologies. Operation and enhancement are hereby calculated under a systemic point of view, i.e. no supplementary costs for the purchased energy are considered for the optimization run. To compare the run with the other runs, taxes and fees are considered when balancing the income of storages. This balancing results in a run called V1*, which only differs in the income of storage units from run V1.

The run V2 describes the operation resulting from a systemic optimal enhancement of storages while considering fees and taxes for storage operators. When storage units have to take into account additional costs, a different operation results due to higher price spreads they have to exploit for running economically. Even though, the operation of storages is optimized given a systemic background, i.e. the total costs are optimized, storage units which create additional costs for the system, i.e. they do not run profitably, are not taken into account. The solution thus represents the optimal operation for stakeholders in a systemic optimal environment. Comparing running hours and the income of storage technologies shows the measures to be taken to guide storage units towards a systemic optimal behavior when they are considered as already installed.

The last run, V3, calculates the stakeholder optimum for enhancement and corresponding operation of storages, when additional costs are taken into account. Stakeholders usually perform business cases before investing. Therefore they have to take into account all extra costs, which result from operating a storage unit, amongst others the fees and taxes when energy is purchased. Calculating a business case in a systemic environment allows considering interactions and interferences different technologies oppose to each other. On the one hand the result of this run shows which storage infrastructure results of the stakeholders' point of view, on the other hand it shows how the infrastructure will be operated to represent a valid business case.

Scenario Data

The above mentioned approach demands multiple input data. The fundamental system ISAaR bases on data on conventional power plants, renewable production, storage units, functional storage units, heating plants, thermal storages, the electrical grid, and electrical and thermal consumption. A sectoral coupling is assumed between the sectors electricity, heating and gas through elements like power to heat, power to gas or combined heat and power. The regional resolution is modeled on a country scale. The heating sector is exclusively simulated in Germany and Austria, but in a regional resolution and divided in public and industrial heating. A detailed explanation of the model ISAaR and its input data can be found in /FFE-04 16/.

Among functional storages, several technologies are represented in ISAaR. In households a certain share of the load curves, which is calculated in the optimization runs, of night storage heating, heat pumps and charging of electric vehicles can be changed to generate functional storage options. The delta of the existing load curve and the resulting load curve describes the charging/discharging of the functional storage. The capacity is limited by a time series respecting the temporal depended availability of the elements. The main restriction in the simulation is that the corresponding demand curve must always be maintained.

In the heating sector, power to heat in public supply and industrial demand are also elements that can be deployed flexible. Power to heat can be used to substitute conventional thermal generation and also represents a flexibility option for the electric power system. There is no maximum value that limits the enhancement of capacity and power.

In industries the potential of demand side management (dsm) is represented in three technologies: dsm in electrical intensive industry means shifting consumption from one hour to another and causing production downtimes at certain costs. Load shifting is not connected to additional costs, but its usage is restricted to four times a day and 35 times a year for a maximum period of 4 hours. The maximum installable power is limited to 2180 MW. The costs of production downtimes are assumed to be 300 €/MWh, the maximum installable power of this option is limited to 7220 MW. Demand side management in cross-sectoral applications stands for downtimes or additional runtimes of auxiliaries. It can be used once in 12 hours with a maximum of 500 times a year and with an availability of 6600 h/a, the maximum installable power is limited to 1580 MW.[3]

The assumptions for the additional costs due to fees and taxes are oriented at the current fee policy and consist for example in the EEG surcharge for some technologies or the grid charge[4][5][6]. **Figure 3** displays the supposed total costs for purchased electricity for storages.

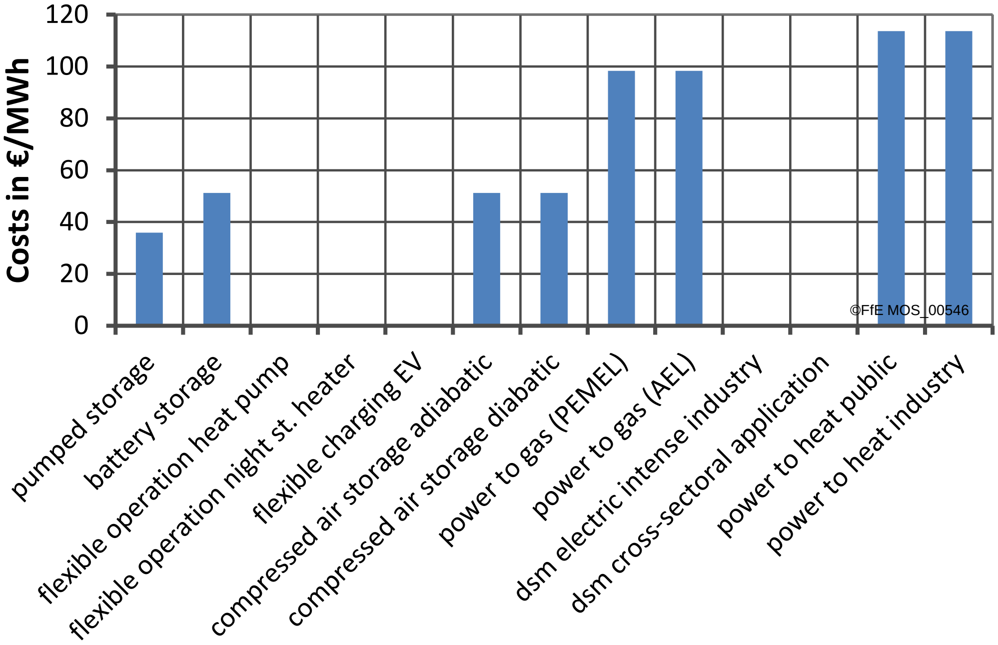

Figure 3: Additional costs for storage units

In the recent cost regulation, pumped storages have an advantage over all other conventional storage technologies, for which reason costs are lower than for batteries or compressed air storages. Demand response technologies, which do not create an additional need of electricity due to their usage as functional storages such as flexible usage of heating pumps or demand side management in industries. It is thus not necessary to charge them with additional costs as the total consumption stays the same in both cases. End consumers, e.g. power to gas or power to heat have to pay higher taxes than storage units, whereas power to gas is favored in the recent cost regulation. It is obvious that some fees and taxes will vanish until the year 2030, but

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[3] C. Pellinger, T. Schmid, et al.: Merit order of storages 2030, FfE e.V. Munich, 2016

[4] §12 Abs. 1 Nr. 2 StromStV

[5] EEG §37 Abs. 4

[6] §9a StromStG

others will appear. Therefore the recent regulation is used as a benchmark for a possible regulatory system in 2030.

Results

Taking into account a stakeholder perspective for the enhancement and operation of storage units has an important influence. While the installed capacity and the operation hours of some technologies do not differ between the systemic point of view and the stakeholder optimum, the behavior of other technologies changes completely.

In the first run V1, the system optimum is determined, where no additional costs are taken into account. **Figure 4** shows the installed power that results from the optimization run V1 and is thus also valuable for the run V2.

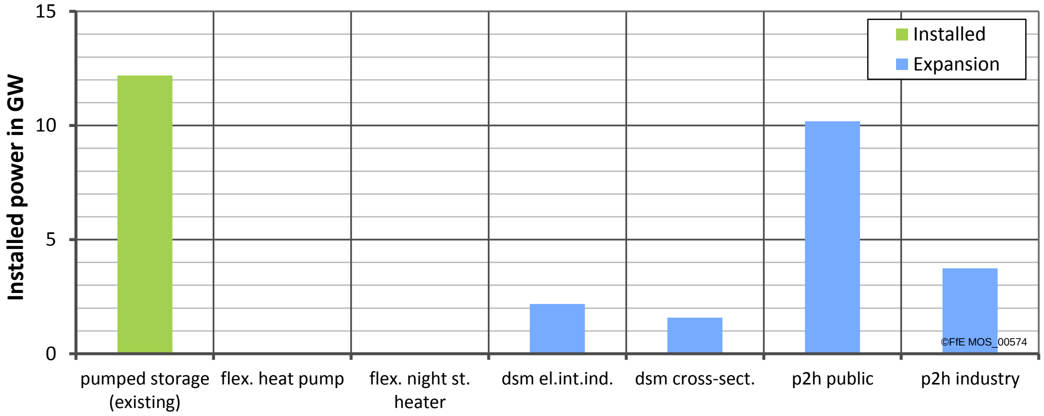

Figure 4: Installed power of storage units in Germany and Austria in 2030 for the runs V1 and V2

The only units which are considered as already installed from a nowadays perspective are pumped storage facilities. Their output power is determined to 12 GW in Germany and Austria. In the system optimum, neither heating pumps (**flex. heat pump**), night storage heaters (**flex. night st. heater**) or charging of electric vehicles (not in the figure) are used as flexible option. The potential of demand side management in electrical intense industries (**dsm el.int.ind.**) and of demand side management of cross sectoral applications (**dsm cross-sect.**) are installed to their full capacity. For power to heat in public supply (**p2h public**) more than 10 GW are installed and for power to heat in industries (**p2h industry**) nearly 4 GW. Technologies which are not in the picture like pumped storage, battery storage or compressed air storage are not installed in any run.

To determine how often elements are used full load hours are calculated. Typically, the operation of storage units is described with the number of cycles, which takes into account the capacity of the storage element. As for some elements, like the flexible implementation of night storages, there is a time series of available capacity, it is not possible to determine the number of cycles. Therefore the ratio of the overall energy that reaches the storage and the maximum output power is calculated as full load hours. The full load hours of storage technologies in the run V1 are shown in **Figure 5**.

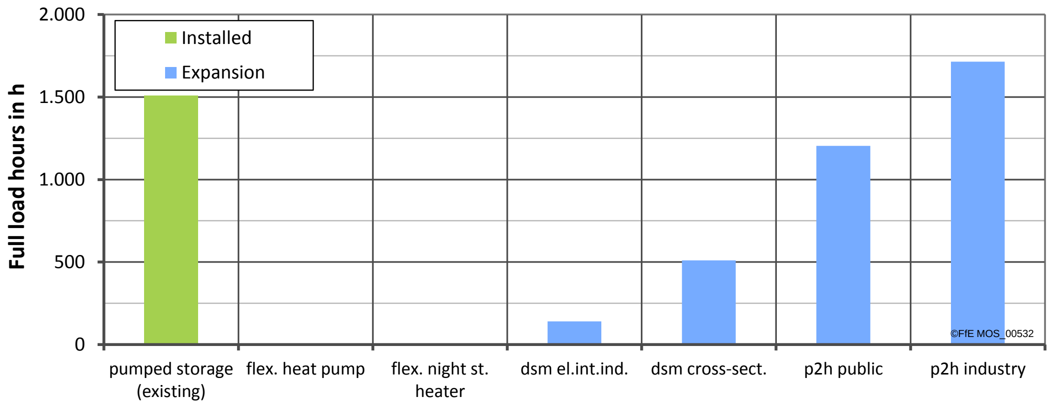

Figure 5: Full load hours of run V1

Pumped storage units reach 1500 h of full load, while dsm el.int.ind and dsm cross-sect reach the maximum of possible full load hours (140 h and 500 h). The full load hours of p2h in public supply and p2h in the industry are 1200 h and 1700 h.

For the system optimum, the conclusion can be drawn, that beside demand side management in industry, power to heat represents the second option for further enhancement of flexibility. As pumped storage units are already assumed being installed, they are used for load shifting in times when no additional costs for the system result from the operation.

Regarding the benefits and losses of technologies of V1 from a stakeholder’s perspective, costs and earnings are calculated in a version V1* where fees and taxes for the operation are considered.

In **Figure 6**, when a systemic optimal behavior is assumed, but fees and taxes are taken into account, it is obvious, that most of the technologies face supplementary spending, which results in a loss.

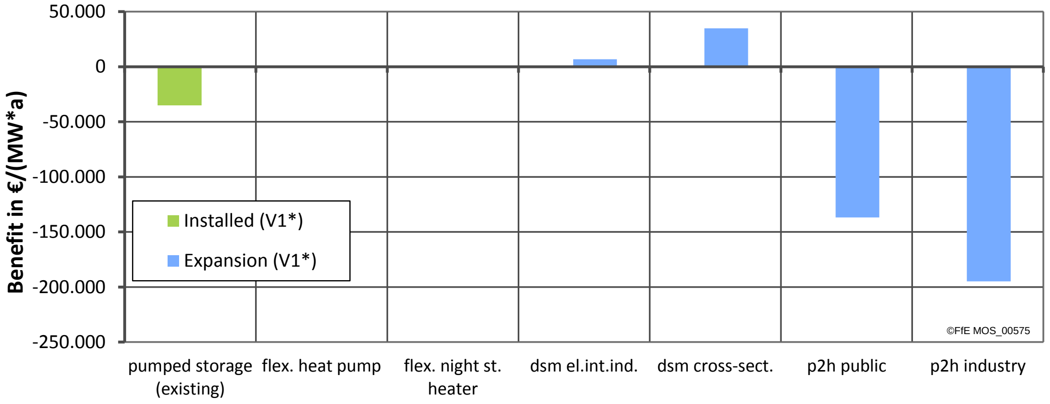

Figure 6: Benefits of technologies in V1*

Only the dsm technologies generate benefits for their owners, due to no additional costs they have to face when being operated as a functional storage. The losses show the costs that have to be compensated when storage units should run as they do in the system optimum to make the technologies financeable from a stakeholder’s perspective and to make them run with a systemic optimal behavior.

The run V2 faces the question, how storage units would operate, when the enhancement is fixed due to the system optimum from V1, but the units operate in a stakeholder's optimum. This run does not only give an idea of changes in operation, but allows calculating the additional costs that result for the system due to a different behavior of storage units.

As the installed power of storages is kept the same from run V1, in **Figure 7** the full load hours of the different technologies are displayed.

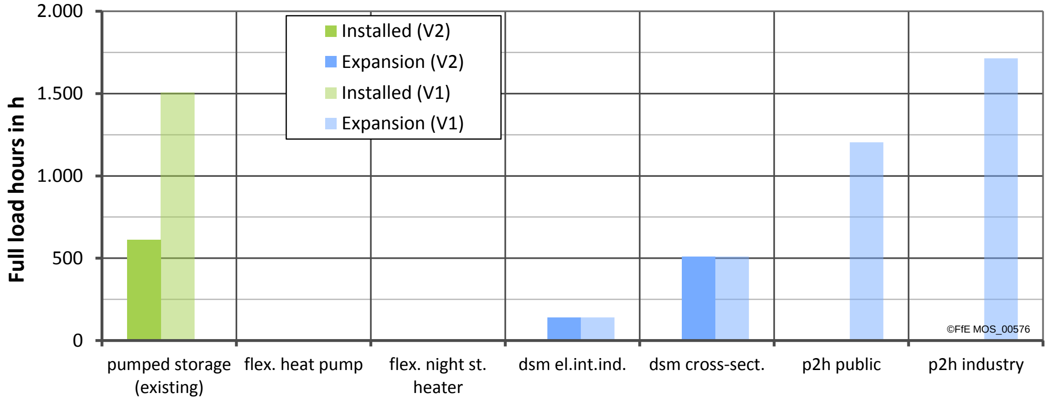

Figure 7: Full load hours in V2 and V1

Comparing the two runs V1 and V2 outlines a vast difference in operation for all technologies that are affected by fees and taxes. The operation hours of pumped storages are reduced by more than 60 %, power to heat elements do not run anymore. The additional expenses caused when energy is purchased lead to higher savings that need to be produced by pumped storages in the event of operation. Power to heat elements on the other hand compete against conventional heat generation by mostly gas conducted heat plants. Due to the additional costs of 113 €/(MW*a)h, they are no longer an economically expedient substitution, as the maximum shadow price for heat generation from heat plants is 70 €/(MW*a)h. Only the dsm technologies are not affected by the change of the cost regulation as they do not induce supplementary consumption and thus no additional costs.

The described changes in operation lead to additional costs of 885 million € for the system. Some of the different storage units on the other hand are now able to generate benefits due to the stakeholder optimized approach as displayed in **Figure 8**.

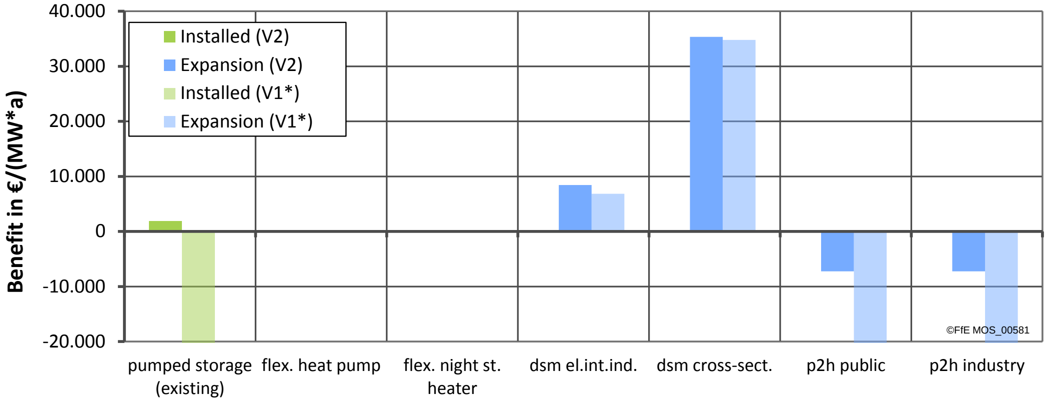

Figure 8: Benefits of storage technologies in V2 and V1 (detail)

Pumped storage units now generate benefits of 2000 €/(MW*a) as they are only operated when they do not cause any additional costs to the system when fees and taxes are considered. As power to heat elements are not operated at all, the losses correspond to their annuity costs. The benefits of demand side management elements in industries are slightly higher than they have been in V1*, as they are in V2 also deployed in moments of high costs savings, which was not the case in the systemic optimum, when competing with other storage options.
The last run V3 determines the optimal scenario from the stakeholder's point of view concerning enhancement and operation of the storages. This leads to an important change of installed storage power as shown in **Figure 9**.

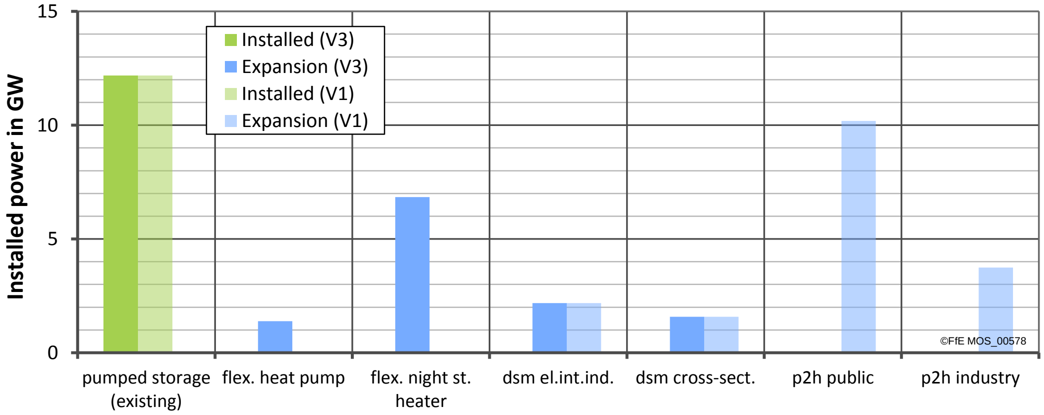

Figure 9: Installed power of storage technologies in runs V3 and V1

While power to heat elements are not installed any more, which can be concluded by comparing shadow costs of heat production with the fees and taxes assumed for power to heat, a vast potential of flexible heating pump operation and flexible night storage operation is made accessible. As these technologies don't induce additional costs during operation, they present an economic replacement for missing flexibility. The overall power of installed flexibility is nearly the same as in the system optimum V1. Comparing the full load hours of both runs as shown in **Figure 10** on the other hand reveals a vast difference in operation.

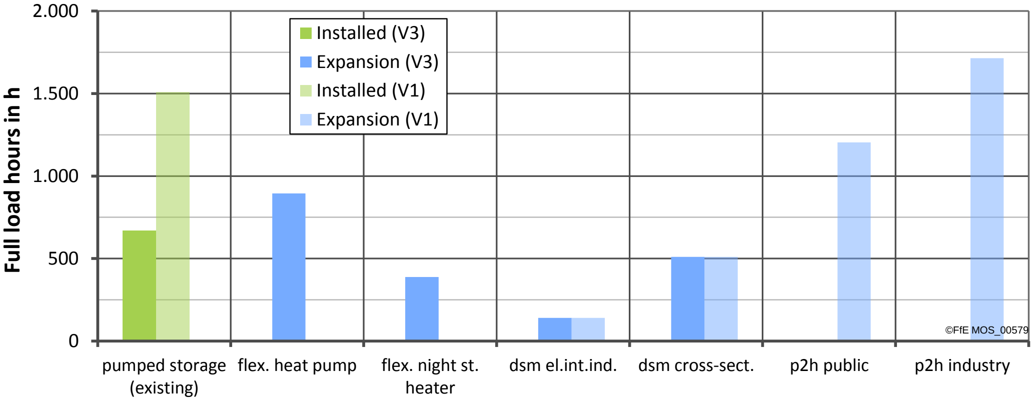

Figure 10: Full load hours of storage technologies in runs V3 and V1

Full load hours of pumped storage units are reduced by more than 50 % as it was the case for the run V2. The main difference is that the missing flexibility in this case is provided by flexible operation of heating pumps and night storage heaters. Enhancement and operation of flexible operated heating pumps and night storage heaters is economically more efficient than running already existing pumped storage units. The operation described for V3 leads to the benefits displayed in **Figure 11**.

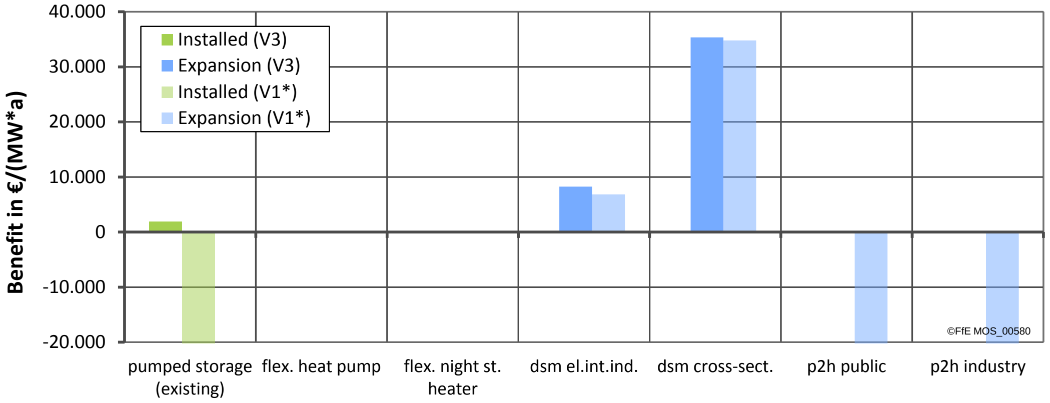

Figure 11: Benefits for storage options in V3 and V1* (detail)

Pumped storages can generate benefits as do the demand side management technologies. The other newly installed technologies don’t produce any benefits or losses. This comportment results from the optimization logic. As a complete competition is assumed in the linear optimization approach, new technologies are enhanced as long as they reduce the total costs of the optimization run. As long as a technology does not reach the technical maximum, as it is the case for the dsm technologies, or as long as the installed power is assumed a given input parameter (pumped storages), technologies do not create benefits or losses. Creating benefits would mean, that further potential could be exploited that reduces the overall costs, losses on the other hand would generate additional costs for the optimization run and thus make the result not an optimal solution. In this run, the total economic costs for the system, i.e. the costs that result without taking into account fees and taxes are 770 million € higher than they are for the system optimum solution in V1.

Conclusion

The described analysis outlines the difference between the systemic optimum solution and the optimum solution from stakeholders’ point of view. Taking into account fees and taxes that are similar to the recent cost regulations for storages conclude in a different perspective of enhancement and operation of storages. Demand side management in industries turns out to be an economic and profitable solution in either case. While the systemic optimum prefers the substitution of conventional heat production with power to heat technology in public and industrial applications, the optimum solution from stakeholders’ perspectives favors demand response technologies like flexible operation of heating pumps and night storage heaters. In all optimization runs, enhancement of conventional storages does not take place. Comparing the overall economic costs of the systemic optimum for enhancement and operation (V1), the stakeholder’s optimum for operation with a systemic optimum enhancement (V2) with a stakeholder’s optimum for enhancement and operation (V3) shows, that with the assumed cost regulatory the overall costs are 320 million € (V2) respectively 300 million € (V3) higher than in the systemic optimum. These costs have to be compared to possibly occurring additional costs when the enhancement and the operation of storages shall be led towards a systemic optimum solution.

Literature:
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[6]) Stromsteuergesetz vom 24. März 1999 (BGBl. I S. 378; 2000 I S. 147), das zuletzt durch Artikel 11 des Gesetzes vom 3. Dezember 2015 (BGBl. I S. 2178) geändert worden ist