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SUSTAINABLE USE OF EXCESS WIND POWER SHARES - A MULTI CRITERIA ANALYSIS OF DIFFERENT GRID- AND STORAGE OPTIONS

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INTRODUCTION

Wind energy that can neither be fed into the grid nor be used regionally must be curtailed. This paper proposes different options to deal with such surplus wind energy amounts in a time horizon until 2020. It assesses their ability to handle the surplus energy in a sustainable way using a multi criteria analysis.

The paper bases on a study that was prepared for the Ministry for Climate Protection, Environment, Agriculture, Nature Conservation and Consumer Protection of North Rhine-Westphalia between 2010 and 2012.

DEVELOPMENT OF EXCESS WIND POWER SHARES

The installed capacities of renewable energies are growing very fast. The necessary grid extension cannot always keep up with this development. As a result, renewable energy cannot be fed into the grid at certain times and has to be curtailed.

This study focuses on the curtailment of wind energy. In the last years, the curtailed wind energy amount in Germany rose from 50 GWh (2004) up to 150 GWh (2010). This makes up about 0.4 % of the German wind energy production in this year [1]. This trend is expected to continue in the next years leading to higher surplus energy amounts. This study focuses on the situation by 2020.

POSSIBLE SOLUTIONS

There are two different approaches to avoid the curtailment of renewable energy: The energy can either be transported to another place to meet an existing demand, or the energy can be stored and used in times of demand or free grid capacity.

A spatial shift of energy requires grid extension measures. This means construction of new AC or DC overhead transmission lines or underground cables as well as improving existing power lines. A temporal shift can be achieved with different storage technologies. These include approved technologies such as pumped hydro or CAES as well as new concepts like large batteries or hydrogen storage that can be available by 2020. The following table gives an overview of technology options that are considered in this study.

Grid technologies	extension	DC overhead lines
		DC underground cables
		AC overhead lines
		AC underground cables
	refit	Dynamic thermal rating
		High temp. transmission lines
Storage technologies	chemical	Hydrogen (cavern storage)
		Hydrogen (gas grid)
		Redox-Flow-Batteries
		NaS-Batteries
	mechanical	CAES (status)
		CAES (adiabatic)
		Pumped hydro (status)
		Pumped hydro (new concepts)
		Curtailment

This is a selection of technologies or strategies that can be implemented to deal with surplus wind energy amounts. Since the problem of excess energy amounts already exists and will most likely increase during the next years, the responsible decision makers need to reckon which alternative is to use in which situation. This is urgently necessary since the implementation of some of these technologies may take several years.

RANKING OF TECHNOLOGIES

This study is conducted to rank different alternatives in regard to a sustainable use of surplus wind energy amounts. The word "sustainable" implies economic as well as ecologic and social factors that need to be taken into account. Since one-dimensional approaches such as a cost-benefit-ratio do not suffice, the Multi Criteria Analysis (MCA) is chosen in this context.

Multi Criteria Analysis

The MCA is a decision support method which can be used to solve complex problems with high uncertainties and conflicting objectives. It allows the use of quantitative as well as qualitative data [2].

In the MCA different alternatives are compared against a set of criteria. Therefore, the first step is the definition of suitable criteria. After the criteria have been thoroughly defined, the alternatives are evaluated with regard to these criteria. The third step is a weighting of the criteria. This is done to stress those aspects that are more relevant to the decision maker. Finally, the weighted sum of the evaluations delivers the scores that the alternatives achieve.

The following subsections describe the steps during the conduction of the MCA.

Definition of Criteria

The criteria used in an MCA must fulfill certain requirements. They need to address all characteristics of the alternatives that are relevant for the decision making. At the same time they must be free of redundancies to avoid bias.

The definition of criteria for this study was done in a multi-level process. For each criterion a detailed definition was recorded. The criteria are assigned to four categories. These categories are borrowed from the three pillars of sustainability (Economy, Society and Environment) supplemented with a fourth category to address technological issues. The following table shows the criteria that were chosen in this project. The right column of the table contains the weighting factors that will be explained in the subsection "weighting".

TECHNOLOGY	**33 %**
Efficiency	7%
Implementation time	2%
Innovation potential	4%
Market potential	10%
Controllability	1%
Degree of coverage	7%
Additional uses	3%
POLITICS & SOCIETY	**9 %**
Compliance with political goals	0%
National independence	1%
Employment potential	4%
Social acceptance	2%
Effects on the landscape	1%
ECOLOGY	**29 %**
Resources	5%
GHG Emissions	16%
Other Emissions	1%
Interference with sensitive ecosystems	5%
Risk in cause of failure	2%
ECONOMY	**29 %**
Specific cost	21%
Enhancement of competition	3%
Export potential	5%

Evaluation

Once the criteria are defined, the alternatives are evaluated against these criteria. This evaluation is done using different methods; among these are the review of existing literature, expert interviews and own calculations.

Since there are quantitative as well as qualitative and positive as well as negative criteria, a scale must be defined for each criterion. Therefore, the best alternative in a criterion is assigned the value "10", the least suited alternative scores “0”. The other alternatives score according to a linear scale between these extremes. If an alternative cannot be evaluated it is given the neutral rating “5”.

Weighting

There are many different weighting methods that can be used in the MCA. In this study, the Analytical Hierarchy Process (AHP) was used. This weighting method offers a comprehensible and well documented process of weighting during which the decision maker is able to come to clear prioritisations.

To use the AHP the criteria must be grouped into hierarchical categories. In each level the criteria are compared pairwise. Their priority is rated on a scale between “1/9” (much less important) and “9” (much more important). This leads to a square matrix of priorities. The Eigenvector of this matrix assigned to the single real Eigenvalue results in the weighting. In this process, conflicting or inconsistent ratings can be unveiled and corrected. A more detailed description of this process can be found in [3].

In this study the AHP results in the weighting factors shown in the table above.

RESULTS

To generate MCA results for an alternative, each criterion’s value is multiplied by the criterion’s weighting for each alternative. The sum of products is the overall score of this alternative.

Outcome of the MCA

The MCA conducted in this project leads to the following scores of alternatives with regard to the sustainable use of surplus wind energy amounts:

RANK	ALTERNATIVE	SCORE
1	Dynamic thermal rating	68
2	DC underground cables	67
3	DC overhead lines	66
4	CAES (adiabatic)	65
5	AC overhead lines	64
6	High temp. transmission lines	64
7	Pumped hydro (new concepts)	59
8	*Curtailment*	*59*
9	Pumped hydro (status)	56
10	Hydrogen (gas grid)	56
11	AC underground cables	55
12	Hydrogen (cavern storage)	54
13	Redox-Flow-Batteries	47
14	NaS-Batteries	43
15	CAES (status)	39

The dynamic thermal rating of overhead transmission lines achieves the highest score. It reaches high values in ecological as well as in economical and in the highest weighted technological criteria. The other grid extension measures except for the AC underground cables are also rated high. Adiabatic CAES is the only storage technology that is considered significantly better than the curtailment, which achieves a medium score. Pumped Hydro scores similar to curtailment. Hydrogen and battery storage are ranked lower. Conventional CAES are rated the least preferable alternative to handle surplus wind energy because of their low ecological and mediocre economical and technological scores.

These results reflect the situation in the year 2020. For later years, there will be different scores since some technologies will be more mature, as well as different weighting since e.g. the efficiency might be rated higher due to higher surplus amounts.

Robustness of Results

The results of an MCA are strongly dependent on the weighting. Since most of the considered technologies have a long operating time, it is possible that priorities could change during their lifetime. Hence, a decision for a technology should be robust to changing priorities. To investigate the stability of results, different weighting factors were applied. In addition to the basis weighting explained above, one equal, one slightly and one strongly ecological and one slightly and one strongly economical weighting have been constructed. The effect on the different weighting factors is shown graphically in the slides accompanying this paper.

The dynamic thermal rating as well as the DC underground cables are considered robust, whereas the AC and the DC overhead lines score high in the basis and economical, but rather low in the ecological weighting variants. The hydrogen storage options both reach rather good results under ecological preference, but only poor scores in the other variants. Batteries and conventional CAES achieve rather low results in most weighting variants and are therefore no suited alternative by 2020.

CONCLUSIONS

The Multi Criteria Analysis is a valuable tool to assess multi dimensional problems in energy decision making. Due to its clear structure, it helps to distinguish the relevant criteria and unveils the priorities behind decision making.

When taking into account technological, social, ecological and economical factors, this study comes to the result that dynamic thermal rating for overhead transmission lines, DC underground cables and adiabatic CAES are the best options to deal with excess wind energy amounts in a sustainable way. Storage technologies, except for adiabatic CAES, are considered less suited for this purpose than the curtailment of the excess energy.

REFERENCES

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ABBREVIATIONS

AC: Alternating Current

AHP: Analytical Hierarchy Process

CAES: Compressed Air Energy Storage

DC: Direct Current

GHG: Green House Gas

MCA: Multi Criteria Analysis

NaS: Sodium (Na) Sulfur (S)