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POLITICAL AND ECONOMIC COURSE TO INTEGRATE ENERGY EFFICIENCY IN THE INDUSTRIAL PROGRESS

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Abstract: A green economy requires industrial companies which show a high degree of resource efficiency as well as competitiveness. In times of climate change, energy efficiency represents a major aspect due to its large impact on the reduction of greenhouse gas emissions. Nowadays, energy efficiency means not only consuming less energy, but also using it in times when large amounts of renewable energy is available. From the perspective of the industry, the pursuit of energy efficiency can only be supported if it is integrated as an additional production target. This paper aims at the analysis of legal frameworks and market conditions that encourage the industry to include energy efficiency into their operative management. For this purpose, a model is regarded that realizes a holistic optimization of industrial energy consumption, regional renewable energies and energy storage in a local group of companies. It specifically focuses on the integration of production optimization in a local smart grid context. On this basis, recommendations of actions in economy and politics are derived through the simulation of several what-if-scenarios. The foundation of the analysis builds empirical data from companies in Germany. The central results can be summarized in three observations. First, adequate fluctuating energy prices can be used to motivate the implementation of energy efficiency as target in the production management. Second, a bidirectional demand charge can stabilize a local smart grid. Third, the redistribution of avoided costs for grid expansions can support the installation of energy storages. A future task is the validation of the results in empirical field tests.

Keywords: energy efficiency, green economy, industrial energy management, local smart grid

Introduction

The expression “Green Economy” combines two different kinds of social influences. Today, the word “green” symbolizes several concepts to improve the way we treat our planet. Green are ideas that reduce waste and pollution. Green are sustainable strategies for fishery and agriculture. Green can also be the way, how we produce things in a factory. This includes the careful use of resources as well as the impact of the product during its term. The second aspect of a green economy is the social prerequisite that the wealth of a society depends today mainly on the performance of its economy compared to other societies. This induces the risk of working against each other within each country and in transnational negotiations. While a green concept is always based on the belief in harmony, a free economy is based on the belief in competition. The combination of both, green concepts and economic perspectives is therefore not an easy task. However, there is a vital interest in this field, because of the high potential to introduce green concepts in all parts of the society, when this is directly linked to any economic advantage. In another formulation, it will be very hard to reach any green goal on a large scale without any economic successful model that is enabled by the political and economic framework.

In order to concretize these ideas, it is helpful to focus on a specific domain, which will be in the following the field of energy efficiency as part of industrial companies. One example for the search of the optimal political and economic framework to integrate energy efficiency in the economy can be found in the German Energy Transition1). The main targets of the German Energy Transition are the reduction of greenhouse gas emissions, the independence from nuclear power plants, the reduction of energy consumption and the increase of the share of renewable energies in the energy generation2).While in the first years of this big project the installation of

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renewable energies was the first pillar, the aspect of energy efficiency is nowadays the central pillar of the transition. Energy efficiency does not mean only the reduction of energy consumption. In the context of the Energy Transition energy efficiency is about the intelligent usage of energy in the times, when renewable energies have a high output. This way to integrate renewable energies in the energy system needs a combination of intelligent energy consumer, energy storages, and decentralised local optimization in the grid.

The most important energy consumer is the industry3), which indicates that the development of manufacturing companies to intelligent participants in the future energy grid is essential for the energy transition. A central role in this development is the usage of information and communication technologies, which are necessary to enable the complex optimization in a local energy system that is penetrated by highly volatile renewable energy generation.

A project that focuses on the technical view on this challenge is called EWIMA4) (project number: EFRE-08000681). The goal of EWIMA is the prototypical implementation of regional virtual power plants in north rhine-westphalia, Germany. The central component is an internet of things platform that allows on the one hand a highly advanced energy management for each industrial company and enables on the other hand a cross-company cooperation to optimize the integration of renewable energies locally and to increase the degree of energy efficiency in the region. One big issue that appears continuously during the project whenever it is tried to integrate the sustainable concepts in the industry are the difficult political and economic general conditions. There are several barriers that complicate the technological progress, especially in the field of self-consumption regarding renewable energies, usage of energy storages and local cross-company optimization of energy usage. The reasons are missing or misleading legal requirements and the absence of energy markets that represent regional needs due to the decentralisation and the volatility of energy generation in the course of the energy transition. The goal of this paper is to emphasize the impact of the dimensions of the political and economic course for the integration of energy efficiency in the industrial progress. The ability to realize these concepts of a green economy in this field depends highly on the political and economic framework. Therefore, we analyse in this paper the effect of different measures that support a progress in energy efficiency.

Technical approaches to realize a holistic industrial management are already presented during the project. In 5) information flows and optimization in an energy information system are shown, while in 6) the role of data analytics was highlighted. Basis for the research in this field were several works that describe industrial companies as consumer in the future energy systems from a grid perspective as in 7) and 8). A gap in the research so far is the analysis of technical possibilities for given legal requirements from an industrial perspective.

In order to analyse the political and economic possibilities to support sustainable high tech approach as they are developed in EWIMA there is a need of models that regard a manufacturing company from a production planning and control perspective but as part of a local energy system. Thus, the paper starts with the introduction of a mathematical model, which allows us to analyse the effect of a political and economic course. The next chapter is about the results of this analysis. The paper ends with a conclusion which translates the results into proposed political and economic actions to support the integration of energy efficiency in the industrial progress.

Mathematical Model

The mathematical model should help us to understand the effect of economic and political measures on the possibilities to integrate energy efficiency in industrial companies. We regard a local system that consists of a combined heat and power plant, energy storage and production machines as energy consumers. Further, the system involves fluctuating renewable energies, since a volatile energy price will be used that corresponds to the availability of regional generated energy.

We regard the model in a fixed time interval $t = 1, \dots, T$, where each t can be without any loss of generality equivalent to an hour. The combined heat and power plant is modelled

$$E_t^G \in [E_a^G, E_b^G],$$

$$S_0^G - \sum_{t=1}^{T} E_t^G \in [S_a^G, S_b^G],$$

whereE_t^G is the bounded mean of the power that is generated by the power plant in each interval. Further, we regard the power plant as limited energy source where for example a gas storage is used. This is due to the assumption that we regard renewable energies and can only regard biogas in the case of the combined heat and power plant. Then, S_0^G is the initial level of the gas storage and S_a^G, S_b^G its lower and upper bounds.

As energy storage we can regard for example an industrial battery, which can be modelled as[9)]

$$C_t \in [C_a, C_b], D_t \in [D_a, D_b],$$

$$S_0 + \sum_{t=1}^{s} \alpha_C C_t - \frac{1}{\alpha_D} D_t \in [S_a, S_b].$$

Here, C_t and D_t indicate the charging and discharging of the energy storage which has an initial level S_0 and again an upper and a lower boundsS_a, S_b. Further, there are some efficiency losses in the charging and discharging process which are indicated with the parameters α_C, α_D.

The only energy consumers is the production as central component of an industrial company, since we want to focus here on the integration of energy efficiency in manufacturing. In practice, one should include here the facility management and other consumers as well. We assume that there are two production targets. The first target is the minimization of energy costs and the second target is the finish al jobs in time. The factory is modelled as N pairwise independent production machines. The power of each production machine is linear to the number of produced things and can be controlled continuously in this model. Each machine can produce only one product, so without loss of generality we can assume that every machine has only one specific job to do.In general, we have $j = 1, \dots, J$ jobs, which nee to be done on machine n_j and consist of M_j products which need to be finished at time t^j. Every machine has a translation factor c_i from energy to the number of produced products. Then the total energy consumption of the factory can be summarized as

$$E_t^P = \sum_{i=1}^{N} {}^{n}E_t^P,$$

where

$${}^{n}E_t^P \in [\,{}^{n}E_a^P, \,{}^{n}E_b^P],$$

$$c_{n_j} \sum_{t=1}^{t_j} {}^{n_j}E_t^P = M_j.$$

The optimization system can be describes via

$$\min_{E^P, E^G, E^S} \sum_{t=1}^{T} P_t^{in} (\Delta E_t)_+ + P_t^{out} (\Delta E_t)_- + P_d \max_t |\Delta E_t|,$$

with energy difference

$$\Delta E_t = E_t^P - E_t^G + C_t - \frac{1}{\alpha_D} D_t.$$

The parameter P_d indicates a bidirectional demand charge, while P^{in} and P^{out} are the prices to consume energy from the grid or to feed it back. Here, we use the assumption that large power plants will disappear in the course of the energy transition and we get a market of prosumer which ca be handled in a kind of peer-to-peer-system.

It is easy to see that it must hold $P^{out} \leq P^{in}$ to get a market which is free of arbitrage and the difference between both could for example taxes.
The system can be reformulated with the variable introduction

$$x = \left(E^G, \, {}^nE^P, C, D\right)$$

to the following form

$$\min_{x \in \mathbb{R}^{(3+n)T}} \sum_{t=1}^{T} P_t \Delta E_t \, P_d \max_t |\Delta E_t|,$$

with$10 + 3n$ conditions for $1 \leq t \leq T$

$$x_t \in [E_a^G, E_b^G],$$

$$S_0^G - \sum_{t=1}^{T} x_t \in [S_a^G, S_b^G],$$

$$x_{nT+t} \in [\,{}^nE_a^P, \, {}^nE_b^P],$$

$$c_{n_j} \sum_{t=1}^{t_j} {}^{n_j}x_{n_jT+t} = M_j,$$

$$x_{(1+n)T+t} \in [C_a, C_b],$$

$$x_{(2+n)T+t} \in [D_a, D_b],$$

$$S_0 + \sum_{t=1}^{s} \alpha_C x_{(1+n)T+t} - \frac{1}{\alpha_D} D_{(2+n)N+t} \in [S_a, S_b].$$

Results

Based on the mathematical model, we can analyse the influence of several political and economic basic conditions. The results of the analysis can be summarized in three categories. First, the integration of energy efficiency in the production planning is possible with the concept of fluctuating energy prices that influence the energy costs of the production. The economic potential depends on the ability of a company to react flexible on the demands of a possible local and highly volatile electricity market.

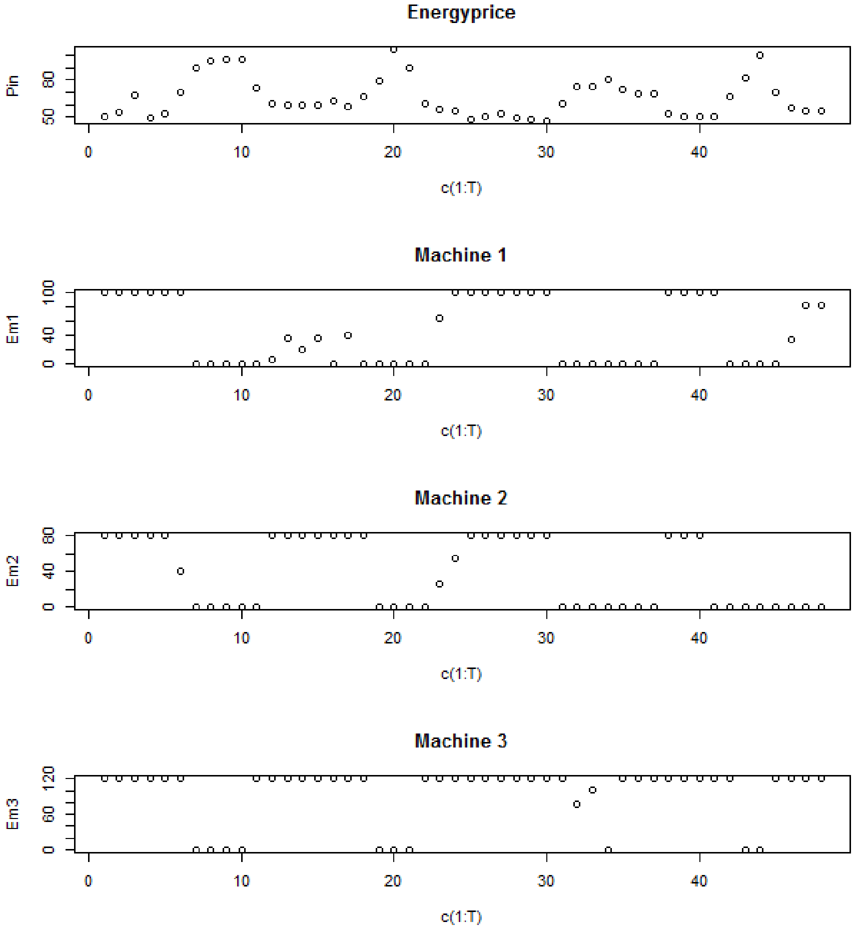

Figure 1: The effect of fluctuating energy prices in an energy efficient production planning

On the example of three machines in a production, figure 1 shows that in times with high energy price the machines need only little energy, while load peaks are basically in times of low energy prices. The horizontal axis shows the time, while the vertical axis describes the electricity prices respectively the electric power at each machine. The ability to shift loads depend highly on the capacity of each machine. While the third machine has too many jobs and is therefore less flexible regarding its energy consumption, the second machine avoids completely high energy prices.

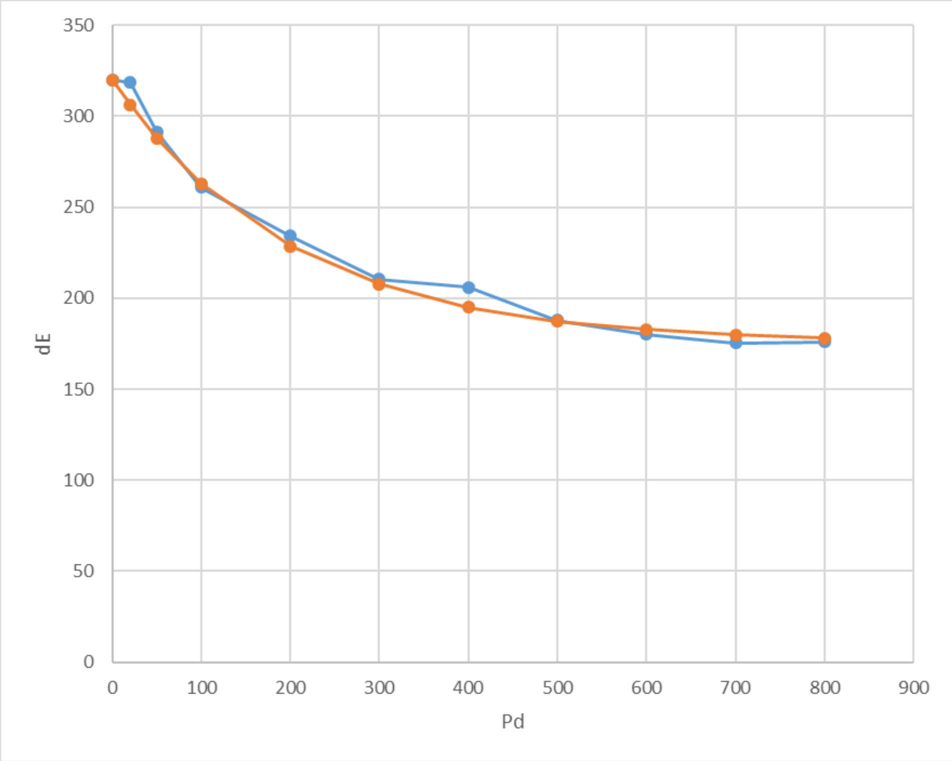

Figure 2: Bidirectional demand charge (x-axis) and maximal difference between energy consumption and energy generation (y-axis) with model results (blue) and regression (orange)

The second observation in the results is that a bidirectional demand charge can be an answer to the trend that energy generation is more decentralized today and thus many companies are energy generators themselves. Figure 2 shows how the maximal difference between local consumption and local generation of energy decreases with increasing demand charge. The result from the mathematical model can be approximated with an exponential function. The limit is reached at the point, where the production uses its maximal flexibility in energy consumption without neglecting the other production target to finish all jobs until a specific date.

The third main observation is the positive effect of energy storages regarding the volatile generation from renewable energies. Figure 3 shows three scenarios with different capacity of the energy storage in the mathematical model. The capacity range was between 80 and 400 kWh, where the charging and discharging is limited by $1/(4h)$ of the capacity. While the maximal change in the energy or power difference is limited by about 160 kWin the case of a 80 kWh storage, the power can change up to about 350 kW from -150 kW to 200 kW in the case of a 400 kWh storage.

The combination of the second and the first observation shows us, that the energy storage will be used more to reduce the maximal demand when the bidirectional demand charge is higher. Thus, the balance between energy prices for energy consumption and the demand charge can be essential to balance the electricity grid and reduce the costs for grid expansions.

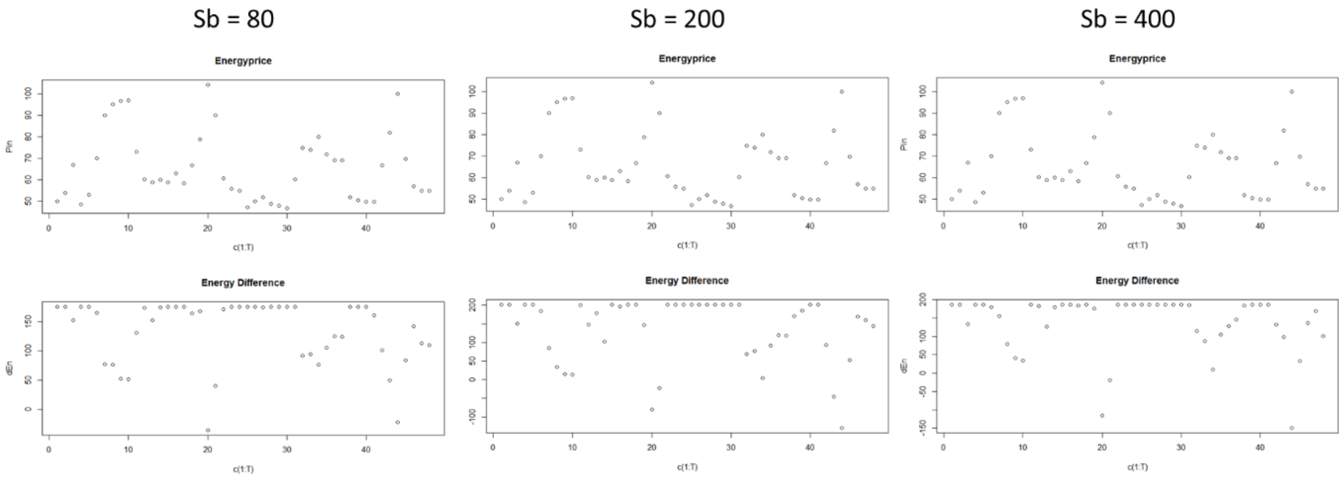

Figure 3: The role of energy storages in local optimization. Three scenarios with different energy storage capacity (Sb) in kWh, where the x-axis shows the time and y-axis shows maximal energy difference in the lower graphs and energy prices in the upper graphs.

Conclusion

The results show that the political and economic framework has a big impact on the degree in which energy efficiency will be implemented in the industry. Tax refunds for energy storages could be financed regarding the avoided costs for grid expansions and could insure that energy is consumed locally where the decentralized energy generation is now placed. Further, we need a market mechanism that allows regional, volatile energy prices for smaller and medium companies as well as for large companies. Now, volatile energy prices are available at the European sport market. However, this is not an adequate tool to insure local balance of consumption and generation and to include smaller energy consumers. Thus, the introduction of regional decentral energy markets that are coupled with the European energy market and the local conditions could help to support the decentralisation that is an obligation for the energy transition. Another aspect is the introduction of bidirectional demand charges, since the demand charge depends only on energy consumption at the moment. But, this reflects not the current decentralized structure of renewable energy generations where we have a lot of energy injection in the distribution grids.

For all ideas, it is essential that the political decisions insure that the economic framework is fixed for a long time period so that it is possible for enterprises to develop long-term strategies that are necessary regarding the high investment costs in energy storages and energy information systems that can handle the complex local optimization. The proposed course can be developed by politicians and the energy economy in direct cooperation with innovative, sustainable industrial companies.

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