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Augmenting Energy Flexibility in the Factory Environment

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Abstract

The increasing share of renewable energies in modern energy systems requires effective solutions to help harmonizing energy supply and demand. Fluctuating energy prices have been incentivizing customers, including manufacturing companies, to identify and build up technical solutions and abilities to profit financially from fluctuating energy prices. Therefore, energy flexibility has gained major attention in research and among industry practitioners. This paper overviews the topic of energy flexibility and discusses associated opportunities, risks and trends. Besides, an assessment methodology to identify potentials for energy flexibility in the factory environment is proposed. Furthermore, practical and conceptual examples to augment energy flexibility in the factory environment are given. In addition, a new concept for (energy) flexible factory environments is presented.

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Keywords: Energy Flexibility; Sustainable Manufacturing; Factory Design; Renewable Energy; Product Service Systems

1. Introduction

1.1. Problem

Improving sustainability of manufacturing operations is one of the dominant research topics since many years [1, 2]. The developed methodologies focus on energy and resource efficiency [3-5], renewable energy usage [6, 7], and imply life cycle and circular economy thinking in order to find solutions on how to deal with waste streams and old products [8, 9]. Researchers discuss the advantages of product service systems [10, 11] and the concept of industrial symbiosis in eco-industrial parks [12-14].

In this context, the increasing share of low-carbon energy production in Germany and the world is a promising trend [15]. It has the potential to support the efforts towards greener manufacturing operations by substituting conventional carbon-based energy sources by renewables. Accelerating this transition in a needs-oriented and financially viable way, calls for methodologies and practical approaches that deal with the unsteady availability of renewables. The evolution of existing grids towards smart grids and virtual power plants, the build-up of storage capacities and the increase of demand-side flexibility are complementary approaches to cope with this challenge [16, 17].

In manufacturing, energy flexibility is understood as "[...] the ability of a production system to adapt itself fast and without remarkable costs to changes in energy markets." [18] Given the documented research on the topic [19-22], the authors find that there is further need for contextualization in order to communicate the relevant opportunities and associated risks to industry practitioners.

1.2. Flexibility in manufacturing: state of science

Flexibility has been a goal in manufacturing for more than 40 years [23, 24]. Hence, the novelty of the concept is minor. The strife for increased flexibility has been the answer of manufacturing companies to fluctuating customer demands, including but not limited to:

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- Growing number of individualized products
- Fluctuating demand for products
- Increasing number of changes in product variants and models
- Growing number of product innovations
- Reduced product life cycles

There are several methodologies associated with the topic of flexibility in manufacturing systems. For instance, Schenk und Helbing address the flexibility of system components in the factory environment [25, 26]. The description of flexible manufacturing systems and planning processes, including options for changeability, agility and reconfiguration are described by [27-29]. Besides, Wiendahl et al. give insights into flexibility options when it comes to modular building structures and extensible technical building services (TBS) in single factories [30, 31]. Additionally, a theoretical dynamic approach that considers manufacturing and volatile energy markets is developed by [32].

A new aspect of flexibility in manufacturing is its application in the field of energy supply and demand. Contrary to the afore-mentioned drivers, energy flexibility is no specific customer demand, but a requirement of an evolving energy system that has to deal with an increasing share of volatile and non-dispatchable centralized and decentralized energy sources [33]. On a national scale the changing energy system requires major capital investments in grids and storage technologies in order to secure and uncouple the availability of energy production from its usage [34].

Yet, implying mechanisms that motivate market participants, including manufacturing companies, to increase their demand-side flexibility can be an alternative way to reduce required investments in the energy infrastructure.

1.3. Research Gap & Objective

Today, industry practitioners miss tools to classify the topic of energy flexibility, considering opportunities, risks and trends associated with their individual company. Besides, the assessment of existing and future potentials for increased energy flexibility requires the development of practical methodologies for planning and operation of manufacturing systems. Moreover, several practical uses cases are presented.

Associated with the topic of energy flexibility, literature suggests the design of a flexible factory environment [35]. Hence, in chapter 5 we apply this idea in a concept for flexible energy related factory infrastructures based on modular elements and standardized interfaces. Additionally, the opportunities of TBS that are turned into product-service systems (PSS) for TBS are presented.

2. Opportunities, Risks and Trends

2.1. Identification of potentials for energy flexibility

Implying energy flexibility measures requires a thorough evaluation of the associated cost-potential ratio. Based on interviews with five industry practitioners from production planning, technical services and maintenance the qualitative estimate shown in Fig. 1 was derived (x: 0 = no potential, 4 = high potential; y: 0 = low cost, 4 = high cost).

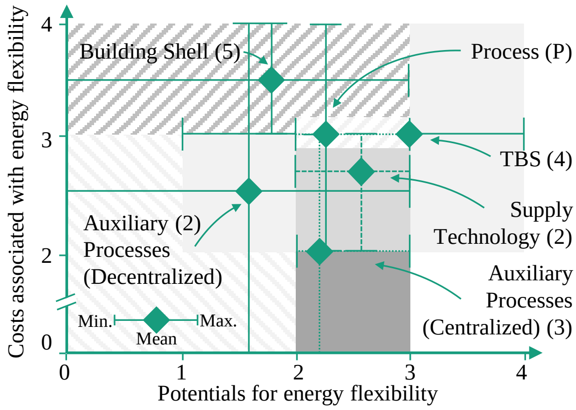

Fig. 1 Cost-potential ratio of energy flexibility measures

In fact, industry practitioners estimate that besides energy flexible processes, systems in the factory periphery such as auxiliary processes, supply technologies and TBS offer potentials to augment energy flexibility. Yet, the interview partners also revealed difficulties on how to address enabling (replacement) investments in the building infrastructure or building shell at management level, since the return on investment is generally low. They also stated that decision makers lack tools to evaluate associated costs and benefits, corresponding to wide ranges in Fig. 1, including side effects such as increasing or decreasing productivity.

Before discussing specific use-cases and ways on how to solve this conflict of objectives the subsequent sections summarize specific opportunities and risks associated with the topic of augmented energy flexibility in the factory environment.

2.2. Opportunities through increased energy flexibility

In brownfield applications the use of existing building infrastructures and TBS, e.g. warm and cold water storage, compressed air storage etc., already offer possibilities for an increased flexibility in the factory environment. Also, redundant structures that are not completely replaced when new systems are installed should be considered as cost-efficient flexibility options.

The time when a modification of a system or system component is required due to regulations, increased maintenance costs, failure or malfunction etc. offers the opportunity to consider flexibility options in the decision process for the replacement investment.

Besides, incorporating flexibility requires the consideration of an augmented use of equipment that is already installed in the factory environment. One example is the use of uninterruptible power supply (UPS) systems that are installed in many facilities due to security reasons (2.5 GW of installed power in Germany (2011) [36]). Possibilities to use these systems, at least partly, can include peak shaving applications or storage of electrical energy from photovoltaic systems [24].