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Supporting The Transformation To Climate Neutral Production With Shop Floor Management

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Abstract

The European Green Deal proposes the transformation to climate neutrality by 2050. Especially for manufacturing companies and their production sites, this transformation is a big challenge. Every aspect of the value stream needs to be re-evaluated and adjusted to reach the new target state of climate neutral production. In the last decades, many companies used lean management methods to improve production in the dimensions of time, quality, and cost. However, a growing number of studies show that lean methods can also be used to drive sustainability goals (with the target state being climate neutral production). This paper analyses the suitability of shop floor management, a popular lean method, in the context of climate neutral production. To this end, a literature research has been conducted to summarize the goals of shop floor management and the success factors for the transformation to climate neutral production. Then the results are contrasted and overlaps are analysed to identify possible shop floor management tools to accelerate the transformation to climate neutral production. Finally, the findings are briefly discussed and summarized in a matrix. The paper closes with specific recommendations for further research in this area.

Keywords

shop floor management; lean management; climate neutral production; climate neutrality; sustainable production

1. Motivation

With the Paris Agreement the United Nations agreed that global warming is to be limited to a maximum of 2 °C and that efforts are to be pursued to remain below 1.5 °C [1]. It was recently reaffirmed at COP26 in Glasgow [2]. This goal requires steps to be taken in all areas of society including industrial production. The manufacturing sector is challenged to integrate the goal of climate neutrality into operational company processes. In the last decades many companies used lean management methods to improve production in the dimensions of time, quality, and cost. An extension of the dimensions is therefore plausible and has already been investigated by several studies [3–5]. The difficulty is that elimination of waste (lean) and resource efficiency (climate neutrality) are dealt with in different committees or working groups [3]. Furthermore, approaches to Lean&Green to date are project-based and still focus on cost reduction as the main dimension [6]. For climate neutral production a much more fundamental and sustainable change in the companies must be achieved [7]. In their lead research study the "Deutsche Energie-Agentur" (dena) describes the change necessary in vision and strategic goals of companies to reach climate neutrality [8]. To operationalise strategic goals the widely accepted lean method of shop floor management (SFM) can be used. In 2018, a study from Germany shows that more than 80 percent of producing companies use SFM to lead workers on the shop floor and help them improve production processes [9]. Since climate neutrality is also a strategic improvement process the question is whether SFM can support the success factors of climate neutral production. However, there is currently a lack of a comprehensive overview of the success factors for climate neutrality in production. Based on that, a comparison can be made to develop recommendations in which areas SFM can promote climate-neutral production.

This paper is divided into three parts. First, the state of the art for both areas is analysed. The second part explores the success factors of climate neutral production through a systematic literature review. Then, matching areas are analysed and recommendations for further research are discussed.

2. State of the art

2.1 Climate neutral production

In recent years, climate targets of various countries and other institutions have been tightened. The goals are often defined by the target state of climate neutrality. The European Union, for example, has set a target in the European Green Deal 2019 to become the first climate neutral continent by reducing net greenhouse gas emissions to zero by 2050 [10] and by 55 percent by 2035 compared to emissions in 1990 [11].

The term climate neutrality must be distinguished from greenhouse gas neutrality and CO_2 neutrality. CO_2 neutrality refers to a state in which as much CO_2 is emitted as is absorbed by natural and technical sinks. Additionally, greenhouse gas neutrality includes other greenhouse gases. Finally, climate neutrality is the condition in which no further increase of global temperatures exists. Since there are many effects on climate change, some of which are not directly measurable, the term climate neutrality is often used synonymously with greenhouse gas neutrality [7,12]. Despite significant reductions in recent years, the industrial sector still accounts for about 20 percent of greenhouse gas emissions of the European Union [10]. Accordingly, there is still a need for action in the industrial sector to further reduce emissions and contribute to the goal of climate neutrality. In addition to the ecological impact the goal of climate neutrality is also gaining importance for companies due to other reasons: The climate targets are becoming an important criterion for investors to base their decisions on. Emission certificates must be purchased, whereby rising prices can be assumed. Rising energy prices also make activities to increase energy efficiency economically attractive. In addition, the demand for climate neutral products on the customer side is growing as well. [13]

A company's emissions are often broken down into three scopes according to the Greenhouse Gas Protocol [14]. Scope 1 includes direct emissions inside the company e.g., from the combustion of natural gas. Scope 2 covers emissions from energy purchases. Scope 3 includes further emissions, for example caused by upstream and downstream processes in the supply chain and the use of the product [15]. In all three scopes, there is a multitude of possible actions for companies to reduce emissions.

The goal of climate neutrality is often examined in cross-sectoral transformation studies for entire national economies [8,16,17]. In addition, there are studies that investigate transformation paths in specific sectors, such as the industrial sector, or specific industries [18]. Nevertheless, for a comparison of shop floor management with climate neutral production, an overview of success factors for climate neutrality is missing. There are guidelines for implementation, but these focus on partial aspects such as resource efficiency [19] or are limited to certain stakeholders, such as managers [8]. Therefore, an overview of the success factors must be created, on which further considerations will be built.

2.2 Shop floor management

SFM originated in lean manufacturing theories and was first introduced by Suzaki in 1993 with the book "The New Shop Floor Management" [20]. On the shop floor goals set by the management are translated into traceable key performance indicators (KPIs). SFM helps to identify deviations in the KPIs, analyse those in shop floor meetings and initiate a problem-solving process. Optimizations developed in the problem-solving process are stabilized and standardized in order to reach a continuous improvement of the production processes [20,21]. The Darmstadt SFM model developed by Hertle et. al. identifies five core elements of shop floor management: performance management, problem management, lean leadership, glass wall management and competence management. For each element several goals and methods are presented in the following paragraphs:

With **performance management** the work scheduling as well as the order scheduling in production is addressed [20–22]. In performance management, a basic distinction is made between two types of improvements: Reacting to problems and achieving more challenging goals [20–22]. A major lean principle for the reaction to problems is the *stabilization of processes* [20,21]. The initial standard is the baseline for further improvement and is controlled through KPIs. If there are regular deviations generated by unstable processes, these must first be addressed [23]. The *definition of goals* for the production processes by management is the prerequisite for the *definition of KPIs* to visualize the degree of target achievement. This goal oriented approach to SFM is linked with the lean method “Hoshin Kanri”, where every KPI or goal is linked to the long-time vision of the company [24]. All entities in the company are encouraged to have the same structure of KPIs to strengthen transparency [25]. KPIs are challenged every day and optimized towards the set goals to *control and increase the production output* [21,23].

In **problem management** the deviations in KPIs are presented to the employees and managers where they must make the decision how to handle the deviation. This can be categorized into three different reactions: If the deviation is not impactful or even a false alarm it can be ignored. If the deviation has an impact on production performance immediate action to prevent further damage or solve minor issues are to be taken. Finally, if the deviation is a major problem a *systematic problem-solving process* (SPSP) is used to find the right countermeasure. [20,21,24]

Lean leadership is strongly linked with the “Genchi Genbutsu” method of lean management [26]. Managers do not spend enough time on the shopfloor and loose connection to the problems of their employees [23,27]. By meeting on the shop floor together with their employees (Go and See), problems can be analysed and addressed faster. To further strengthen this strategy the hierarchical depth of management is reduced and managers are encouraged to be active on the shop floor to see for themselves. [28,29]

The reduction of hierarchical depth also implies a reorganization of the work environment into smaller teams. Through the introduction of mini factories for *visual management*, the teams are responsible for their own area. Employees start to identify themselves with their work and communication with other mini factories is strengthened [29]. Such communication is only possible by the use of tools for transparency like shop floor boards or Andon that enable to analyse production efficiency even as an external visitor [30,31]. In addition, **glass wall management** includes the goal of *information dissemination*. In order to empower employees there is a need for systematic information dissemination from management to their employees [28]. The employee needs to know the goals/vision created by managers to understand their decisions [29].

In **competence management** three goals are identified. As described beforehand SFM involves employees in the continuous improvement process. This *transfer of responsibility to employees* can be seen as an empowerment to carry out adjustments/optimizations of processes independently/together with colleagues [28,32]. Shop floor meetings are held each day at a set time with a series of topics that are discussed in a predefined order. This *structured communication* ensures that all relevant topics are discussed in a set timeframe while still leaving room for open discussion [23]. Moreover, the transfer of responsibility and the structured communication are used to achieve *competence development for employees as well as management*. Competence development on all hierarchical levels is necessary to have constant continuous improvement for the production process [28]. To achieve competence development, employees as well as management are given specific roles such as shop floor operator, manager and team leader [23]. Leading personnel must be developed into methodical coaches willing to set an example for their employees[23,28]. Furthermore, targeted, work-integrated competence development is key for employees [28].

3. Systematic literature review to identify success factors for climate neutral production

To identify success factors for climate neutral production a systematic literature research was conducted on the database of ScienceDirect. Only literature in English was considered. The database of ScienceDirect was scanned with the following search string: (("climate neutral" OR "carbon neutral") OR ("climate neutrality" OR "carbon neutrality" OR "net-zero")) AND ("manufacturing" OR "industrial production" OR "industry"). The query was limited to title, abstract or author-specified keywords. The focus is on articles that show the implications of the goal of climate neutrality for industrial production, and less on the description of specific technologies. From the results of the literature research, 16 success factors for climate neutral production were derived (see Table 1). Contrasting the methods of SFM these were grouped according to technical, organisational and human success factors [33]. The success factors are chosen to ensure that they can be actively influenced by a manufacturing company. External influencing factors such as the development of the regulatory framework or the energy system outside the factory are just as relevant for achieving climate neutrality but are not within a company's direct sphere of influence. They are therefore neglected in this analysis. Requirements for the implementation of the success factors are included in the description.

Table 1: Success factors of climate neutral production

Technical success factor	**Description**
Increasing energy efficiency	*Increasing energy efficiency* is mentioned in a variety of studies across industry as a key success factor for the development towards climate neutrality [8,16,34–39]. The implementation of energy efficiency measures is also of importance because it supports the implementation of other success factors by reducing the overall energy consumption of the industry sector. Energy efficiency measures need to be targeted after identifying potentials for increasing energy efficiency. They can range from improvements in specific machines and processes to complex systemic measures [39]. Besides the ecological effect, energy efficiency measures can contribute to the profitability of a company by reducing energy costs [40].
Increasing energy flexibility	Energy flexibility describes the ability of a system to adapt to changes in the energy market, especially by shifting electrical loads over time[41,42]. Hence, *increasing energy flexibility* on the demand side creates the prerequisite for integrating an increased percentage of volatile renewable energy sources into the energy system. [8,16] Thus, energy flexibility is necessary not only for transforming factories but also the surrounding energy system towards climate neutrality. *Increasing energy flexibility* can be achieved for example by using energy storages or the planned adaption of production processes according to energy forecasts. [41]
Increasing material efficiency	*Increasing material efficiency* contributes to reducing material-related greenhouse gas emissions by efficient product design and reducing the creation of waste during production by ensuring high quality production processes. [8,16,37–40]. The increase of material efficiency as a success factor includes material substitution as well [39].
Reuse of waste heat	The *reuse of waste heat* can be seen as a sub-aspect of increasing energy efficiency. However, it is of such importance for climate neutrality to decarbonise the heat supply that it is listed as a separate success factor. [8,36,43]
Electrification of energy demands	*Electrification of energy demands* can help reduce direct emissions at Scope 1 by replacing fossil fuels [8,12,37–39,44–46]. Heat pumps are a well-known example of those power-to-heat technologies [38].
Using green fuels	*Using green fuels* covers synthetic fuels, hydrogen, and biomass. These fuels can help replace fossil fuels [8,12,16,36–39,43,44,46,47]. The emission reduction is based on the use of electricity to produce synthetic fuels or hydrogen, or the use of biological processes in the case of biomass. Their use is indicated when direct electrification is not an option [16,45].
Using renewable energies	*Using renewable energies* is an obvious success factor and a prerequisite for other success factors such as electrification or the use of green fuels. Companies can both switch their energy purchases to renewable energies and operate renewable energy plants themselves. [8,16,34,35,43,48]

Implementing elements of circular economy	*Implementing elements of circular economy* contributes to reducing the footprint of the used materials and the manufactured goods. [8,16,37–40,44]
Carbon capture and storage/usage (CCS/CCU)	*Carbon capture and storage (CCS)* processes may be used to avoid emissions, for example when the application of the technical success factors described above does not lead to achieving complete climate neutrality [37–39,48–51]. In the terms of *Carbon Capture and Usage (CCU)*, the captured CO_2 can also be reused for other processes [36,44,47].

Organisational success factor	**Description**
Definition and Implementation of a climate strategy	The *definition and implementation of a climate strategy* is an essential step towards achieving climate neutrality. With a climate strategy, the goal of climate neutrality is strategically anchored in the company and the corporate culture to raise the awareness of employees. Sub-goals are defined for example for certain departments or cost centres, and steps are specified to achieve them. [34,37,40,52,53]
Performing energy management	Since a large proportion of greenhouse gas emissions from companies are energy-related, effective *energy management* is necessary. Key aspects are, for example, the creation of transparency regarding energy. It is characterised by a continuous improvement process, such as PDCA described by the ISO 50001[54]. Systematic *energy management* supports the implementation of other success factors such as increasing energy efficiency. [8,35,39,40]
Incentivising emission reduction	*Incentivising emission reductions* may include the introduction of internal carbon pricing or the attribution of energy costs to departments according to their origin. To be effective, incentives for emission mitigation efforts should be communicated effectively. [55–57]
Supply chain engagement	A major part of the emissions arises from the production of goods in upstream processes outside the company's boundaries. They therefore belong to Scope 3 and can be influenced only indirectly by the company. However, companies can act on their supply chain and encourage suppliers to meet emission targets. Hence, *supply chain engagement* is considered a success factor [58].
Offsetting of remaining emissions	Despite the application of various success factors, companies often have emissions that cannot be avoided directly. In this case, the mandatory purchase of emission certificates or the voluntary *offsetting of remaining emissions* can be considered, which can at least reduce the climate-damaging effect of emissions [8,16,38–40,59]. However, the effectiveness of offsetting payments is discussed controversially [60].

Human success factor	**Description**
Commitment of the employees and management	The *commitment of the employees and management* is needed for the successful transformation towards climate neutrality [39]. It is crucial that they see climate change mitigation as a desirable goal [34]. Employee commitment impacts decisions towards sustainability at all levels, especially at the top management level [40,61].
Providing relevant competences	To enable employees to facilitate the development of the company towards climate neutrality and raise awareness for this strategic goal, *providing the relevant competences* or their external availability is necessary [40]. This is particularly the case in SMEs, where it is hardly possible for employees to specialise in the implementation of climate strategies [8,35,40].

4. Aligning shop floor management with the success factors for climate neutral production

After the detailed description of the literature results the relation of success factors for climate neutral production to SFM are analysed and discussed. The aim is to find out what element of SFM can actively support the success factors and to derive recommendations for further research. This is done by comparing the requirements for the implementation described in Table 1 with the elements of SFM. The findings are visualised in a matrix in Table 2.

In total 9 of the 16 success factors can be supported by SFM. These are described in detail in the following paragraphs. The remaining seven success factors cannot be incorporated into SFM. Those are outside of the sphere of influence of classic SFM. *Using green fuels* or *renewable energies* are strategic decisions made by the management or during a production planning process. The same holds for decisions to *implement aspects* *of circular economy* or *carbon capture and storage*. *Supply chain engagement* and the *compensation of remaining emissions* through the purchase of certificates is controlled by the purchasing department as they control where money is spent. Both are not subjects of a production process optimization method like SFM.

Table 2: Aligning SFM with the success factors of climate neutral production

Elements of SFM	**Success factors of climate neutral production**															
	Technical									**Organisational**					**Human**	
	increasing energy efficiency	increasing energy flexibility	increasing material efficiency	reuse of waste heat	electrification of energy demands	using green fuels	using renewable energies	implementing aspects of circular economy	using carbon capture and storage/usage	implementing a climate strategy	performing energy management	incentivising emission reductions	supply chain engagement	compensation of remaining emissions	commitment of the employees	providing relevant competences to employees
Performance Management stabilization of processes, definition of goals and KPIs, control and increase of production output	●	●	●	●						●	●	●			●	●
Problem Management systematic problem-solving process, continuous improvement	●		●	●												
Lean Leadership Go and See, Gemba															●	●
Glass Wall Management visual management, transparency, information dissemination										●	●	●			●	●
Competence Management transfer of responsibility to employees, open communication, competence development										●					●	●

First, the technical success factors *increase of energy* and *material efficiency*, *energy flexibility* as well as *reuse of waste heat* are discussed. To *increase energy efficiency* one of the requirements is to identify potentials for energy reduction. Target values such as those used in performance management could be helpful for identifying potentials since target states are defined and deviations are determined. Deviations from the target state are dealt with in Problem Management. The *increase of energy flexibility* can be achieved by planning production according to energy availability. This is only possible when the processes are stable and therefore predictable. Through standardization in performance management this requirement can be achieved. For example, a standardized process with high energy demand is carried out at the time when the most renewable energy is available and therefore the energy costs are low. The *increase of material efficiency* is dependent on high quality in production processes. All forms of waste are to be eliminated which is in line with the goals of performance management as well as problem management. Another requirement to increase material efficiency is the low-waste design of products. It would be possible to use the proposal system of SFM for ideas to improve the design of components and products.

The first organizational success factor is the *implementation of a climate strategy*. Key elements of a climate strategy are the definition of goals for each department and awareness of every employee about their goals. Via Performance management these goals can be implemented on the shop floor. Through visual management and information dissemination (glass wall management) and an open communication (competence management) the strategy can be spread further and the chances of a successful change in corporate culture may increase. The second organizational success factor is to *perform energy management*. A requirement of an energy management system in line with ISO50001 is to achieve transparency of all energy processes. Once again KPIs in SFM can support this and elements of glass wall management like mini factories transparently display the energy processes. Furthermore, the ISO50001 recommends the use of PDCA (part of the SPSP) to manage energy related problems. For achieving an *incentivising of emission reductions* internal carbon pricing can be implemented. By making carbon emissions tangible in figures through internal pricing, a direct comparison with other areas is possible. The same strategy is applied in SFM with KPIs. A big part of internal carbon pricing is the effective communication to employees to make sure they understand why they are penalised for creating carbon emissions. Glass wall management in the form of mini factories could enhance transparency in that area.

To *provide relevant competences to employees* there needs to be a definition what the "relevant" competences for each employee are. Relevant competences are specified in SFM via the KPIs of each individual employee. The open and structured communication top-down as well as bottom-up as a main benefit of SFM can be a key feature for a successful transformation as well since it supports the requirement to make employees aware of the wastes around them. Furthermore, the goals of glass wall management could not only provide relevant information to develop competences but also support the *commitment of the employees* on the shop floor. On the other hand the commitment of management is shown transparently by Lean Leadership, where managers commit themselves to be active on the shop floor and support their employees.

5. Recommendations for further research

In summary, this paper analysed the suitability of SFM in the context of climate neutral production. After summarizing the success factors for the transformation to climate neutral production, the commonalities between SFM and the success factors were found. The paper identifies a need for further research and testing on two main topics. Topic one is that several success factors are dependent on KPIs to measure, control and improve resource efficiency of production processes. This requires new KPIs for climate neutral production which have played a subordinate role in classic SFM to date and have not yet been described in detail in this context. Following the recommendations by Diez et. al. [24], there is a need for a complete "Hoshin Kanri Tree" defining the goals and KPIs of climate neutral production on all hierarchical levels. A major obstacle here is the delimitation of the resource consumption caused by each individual workstation because of the difficulty to "break down" the savings from e.g., central supply systems that provide compressed air, heat, or cooling to several machines.

The second topic is the competences of employees and management in climate neutral production that need to be improved. To be able to use SFM for the transformation a full description of relevant competences for shop floor personnel as well as management is needed. These so-called competence tables can then be the basis for competence development through SFM.

Both steps form the basis to evaluate if the methods of SFM are suitable to support a climate neutrality strategy. The authors are planning to implement the new approach in a company experienced with classic SFM. The implementation will reveal which further modifications in the methods of SFM are needed to work with the new goal of transforming production towards climate neutrality.

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References

[1] United Nations, 2015. Paris Agreement, Paris. http://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf. Accessed 5 December 2021.

[2] United Nations, 2021. Glasgow Climate Pact, Glasgow. https://unfccc.int/sites/default/files/resource/cop26_auv_2f_cover_decision.pdf. Accessed 7 December 2021.

[3] Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., Benhida, K., 2016. The integration of lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model. Journal of Cleaner Production 139, 828–846.

[4] Titmarsh, R., Assad, F., Harrison, R., 2020. Contributions of lean six sigma to sustainable manufacturing requirements: an Industry 4.0 perspective. Procedia CIRP 90, 589–593.

[5] Petry, M., Köhler, C., Zhang, H., 2020. Interaction analysis for dynamic sustainability assessment of manufacturing systems. Procedia CIRP 90, 477–482.

[6] Abualfaraa, W., Salonitis, K., Al-Ashaab, A., Ala'raj, M., 2020. Lean-Green Manufacturing Practices and Their Link with Sustainability: A Critical Review. Sustainability 12 (3), 981.

[7] Honegger, M., Schäfer, S., Poralla, P., Michaelowa, A., Perspectives Climate Research gGmbH, 2020. dena-Analyse: Klimaneutralität – ein Konzept mit weitreichenden Implikationen, Freiburg i. B. https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2020/dena_BR_Analyse-Klimaneutralita__t_WEB.pdf. Accessed 1 December 2021.

[8] 2021. dena-Leitstudie Aufbruch Klimaneutralität, Berlin. https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2021/Abschlussbericht_dena-Leitstudie_Aufbruch_Klimaneutralitaet.pdf. Accessed 4 December 2021.

[9] Leyendecker, B., Pötters, P., 2018. Shopfloor Management: Führung am Ort des Geschehens. Hanser, München, 125 pp.

[10] European Commission, 2019. The European Green Deal, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN. Accessed 1 December 2021.

[11] European Commission, 2021. 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0550. Accessed 1 December 2021.

[12] Millot, A., Krook-Riekkola, A., Maïzi, N., 2020. Guiding the future energy transition to net-zero emissions: Lessons from exploring the differences between France and Sweden. Energy Policy 139, 111358.

[13] Buettner, S.M., König, W., 2021. Looking behind decarbonisation - What pressure points trigger action?, in: eceee Summer Study Proceedings, Stockholm, pp. 345–354.

[14] World Resources Institute, 2015. The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, Washington. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf. Accessed 1 December 2021.

[15] World Resources Institute, 2011. Corporate Value Chain (Scope 3) Accounting and Reporting Standard: Supplement to the GHG Protocol Corporate Accounting and Reporting Standard, Washington. https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf. Accessed 1 December 2021.

[16] Prognos, Öko-Institut, Wuppertal-Institut, 2020. Klimaneutrales Deutschland: Klimaneutrales DeutschlandIn drei Schritten zu null Treibhausgasen bis 2050 über ein Zwischenziel von -65 % im Jahr 2030 als Teil des EU-Green-Deals. https://static.agora-energiewende.de/fileadmin/Projekte/2020/2020_10_KNDE/A-EW_195_KNDE_WEB.pdf. Accessed 4 December 2021.

[17] International Energy Agency, 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector. https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf. Accessed 27 January 2022.

[18] Agora Energiewende und Wuppertal Institut (2019. Klimaneutrale Industrie: Schlüsseltechnologien und Politikoptionen für Stahl, Chemie und Zement, Berlin. https://static.agora-energiewende.de/fileadmin/Projekte/2018/Dekarbonisierung_Industrie/164_A-EW_Klimaneutrale-Industrie_Studie_WEB.pdf. Accessed 28 January 2022.

[19] Metternich, J., Schebek L., Anderl R., 2021. Fit Für Die Zukunft: Ressourceneffizienz in Produktionsprozessen. TU Darmstadt. https://www.arepron.com/index.php/publikationen.

[20] Suzaki, K., 1993. The new shop floor management: Empowering people for continuous improvement. The Free Press, New York.

[21] Peters, R., 2009. Shopfloor Management: Führen am Ort der Wertschöpfung. LOG_X, Ludwigsburg, 160 pp.

[22] Hertle, C., Tisch, M., Metternich, J., Abele, E., 2017. Das Darmstädter Shopfloor Management-Modell. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 112 (3), 118–121.

[23] Hertle, C., Tisch, M., Kläs, H., Metternich, J., Abele, E., 2016. Recording Shop Floor Management Competencies – A Guideline for a Systematic Competency Gap Analysis. Procedia CIRP 57, 625–630.

[24] Diez, J.V., Ordieres-Mere, J., Nuber, G., 2015. The HOSHIN KANRI TREE. Cross-plant Lean Shopfloor Management. Procedia CIRP 32, 150–155.

[25] Meißner, A., Grunert, F., Metternich, J., 2020. Digital shop floor management: A target state. Procedia CIRP 93, 311–315.

[26] Blöchl, S.J., Michalicki, M., Schneider, M., 2017. Simulation Game for Lean Leadership – Shopfloor Management Combined with Accounting for Lean. Procedia Manufacturing 9, 97–105.

[27] Meissner, A., Müller, M., Hermann, A., Metternich, J., 2018. Digitalization as a catalyst for lean production: A learning factory approach for digital shop floor management. Procedia Manufacturing 23, 81–86.

[28] Hertle, C., et al., 2017. Innovative Approaches for Technical, Methodological, and Socio-communicative Competency Development in Production Areas. Procedia Manufacturing 9, 299–306.

[29] Hertle, C., Siedelhofer, C., Metternich, J., Abele, E., 2015. The next generation shop floor management – how to continuously develop competencies in manufacturing environments. Universitäts- und Landesbibliothek Darmstadt, Darmstadt, Online-Ressource.

[30] Makhija, A., Wickramasinghe, C., Tiwari, M., 2021. 5 - Visual management, in: Jana, P., Tiwari, M. (Eds.), Lean Tools in Apparel Manufacturing : The Textile Institute Book Series. Woodhead Publishing, pp. 131–208.

[31] Müller, M., Alexandi, E., Metternich, J., 2021. Digital shop floor management enhanced by natural language processing. Procedia CIRP 96, 21–26.

[32] Gaitzsch, T., Ziegler, V., 2010. Shop Floor Empowerment – KVP-Implementierung in Schichtteams, in: Moscho, A., Richter, A. (Eds.), Inhouse-Consulting in Deutschland: Markt, Strukturen, Strategien. Gabler, Wiesbaden, pp. 169–190.

[33] Strohm, O., 1997. Unternehmen arbeitspsychologisch bewerten: Ein Mehr-Ebenen-Ansatz unter besonderer Berücksichtigung von Mensch, Technik und Organisation. vdf Hochschulverlag AG an der ETH Zürich, Zürich, 511 pp.

[34] Carlsson Kanyama, A., Carlsson Kanyama, K., Wester, M., Snickare, L., Söderberg, I.-L., 2018. Climate change mitigation efforts among transportation and manufacturing companies: The current state of efforts in Sweden according to available documentation. Journal of Cleaner Production 196, 588–593.

[35] Sovacool, B.K., et al., 2021. Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options. Renewable and Sustainable Energy Reviews 143, 110856.

[36] Zou, C., et al., 2021. Connotation, innovation and vision of "carbon neutrality". Natural Gas Industry B 8 (5), 523–537.

[37] van Sluisveld, M.A., de Boer, H.S., Daioglou, V., Hof, A.F., van Vuuren, D.P., 2021. A race to zero - Assessing the position of heavy industry in a global net-zero CO2 emissions context. Energy and Climate Change 2, 100051.

[38] Bataille, C., J. Nilsson, L., Jotzo, F., 2021. Industry in a net-zero emissions world: New mitigation pathways, new supply chains, modelling needs and policy implications. Energy and Climate Change 2, 100059.

[39] Rissman, J., et al., 2020. Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070. Applied Energy 266, 114848.

[40] Choi, J.-K., Schuessler, R., Ising, M., Kelley, D., Kissock, K., 2018. A Pathway Towards Sustainable Manufacturing for Mid-size Manufacturers. Procedia CIRP 69, 230–235.

[41] Sauer, A., Abele, E., Buhl, H.U. (Eds.), 2019. Energieflexibilität in der deutschen Industrie: Ergebnisse aus dem Kopernikus-Projekt - Synchronisierte und energieadaptive Produktionstechnik zur flexiblen Ausrichtung von Industrieprozessen auf eine fluktuierende Energieversorgung (SynErgie). Fraunhofer Verlag, Stuttgart, 728 pp.

[42] Reinhart, G., Reinhardt, S., Graßl, M., 2012. Energieflexible Produktionssysteme: Einführungen zur Bewertung der Energieeffizienz von Produktionssystemen. wt Werkstattstechnik online (9), 622–628.

[43] Thiel, G.P., Stark, A.K., 2021. To decarbonize industry, we must decarbonize heat. Joule 5 (3), 531–550.

[44] Capros, P., et al., 2019. Energy-system modelling of the EU strategy towards climate-neutrality. Energy Policy 134, 110960.

[45] Imdahl, C., et al., 2021. Potentials of Hydrogen Technologies for Sustainable Factory Systems. Procedia CIRP 98, 583–588.

[46] Naegler, T., Sutardhio, C., Weidlich, A., Pregger, T., 2021. Exploring long-term strategies for the german energy transition - A review of multi-Sector energy scenarios. Renewable and Sustainable Energy Transition 1, 100010.

[47] Ipsakis, D., et al., 2021. Techno-economic assessment of industrially-captured CO2 upgrade to synthetic natural gas by means of renewable hydrogen. Renewable Energy 179, 1884–1896.

[48] Wang, F., et al., 2021. Technologies and perspectives for achieving carbon neutrality. The Innovation 2 (4), 100180.

[49] Gerres, T., Chaves Ávila, J.P., Linares Llamas, P., Gómez San Román, T., 2019. A review of cross-sector decarbonisation potentials in the European energy intensive industry. Journal of Cleaner Production 210, 585–601.

[50] Turner, K., Race, J., Alabi, O., Katris, A., Swales, J.K., 2021. Policy options for funding carbon capture in regional industrial clusters: What are the impacts and trade-offs involved in compensating industry competitiveness loss? Ecological Economics 184, 106978.

[51] Canal Vieira, L., Longo, M., Mura, M., 2021. Are the European manufacturing and energy sectors on track for achieving net-zero emissions in 2050? An empirical analysis. Energy Policy 156, 112464.

[52] Lee, H., 2021. Is carbon neutrality feasible for Korean manufacturing firms?: The CO2 emissions performance of the Metafrontier Malmquist–Luenberger index. Journal of Environmental Management 297, 113235.

[53] Zameer, H., Wang, Y., Vasbieva, D.G., Abbas, Q., 2021. Exploring a pathway to carbon neutrality via reinforcing environmental performance through green process innovation, environmental orientation and green competitive advantage. Journal of Environmental Management 296, 113383.

[54] Energy management systems - Requirements with guidance for use (ISO 50001:2018).

[55] Harpankar, K., 2019. Internal carbon pricing: rationale, promise and limitations. Carbon Management 10 (2), 219–225.

[56] Bento, N., Gianfrate, G., 2020. Determinants of internal carbon pricing. Energy Policy 143, 111499.

[57] Gorbach, O.G., Kost, C., Pickett, C., 2022. Review of internal carbon pricing and the development of a decision process for the identification of promising Internal Pricing Methods for an Organisation. Renewable and Sustainable Energy Reviews 154, 111745.

[58] Mahapatra, S.K., Schoenherr, T., Jayaram, J., 2021. An assessment of factors contributing to firms' carbon footprint reduction efforts. International Journal of Production Economics 235, 108073.

[59] Stede, J., Pauliuk, S., Hardadi, G., Neuhoff, K., 2021. Carbon pricing of basic materials: Incentives and risks for the value chain and consumers. Ecological Economics 189, 107168.

[60] Barron, A.R., Domeshek, M., Metz, L.E., Draucker, L.C., Strong, A.L., 2021. Carbon neutrality should not be the end goal: Lessons for institutional climate action from U.S. higher education. One Earth 4 (9), 1248–1258.

[61] Kohn, K., Seyfried, S., Weyand, A., Weigold, M., 2021. Energieeffizienz als ein Ausdruck der Nachhaltigkeit produzierender Betriebe. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 116 (1-2), 34–38.

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