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Dresden Model of Adaptability: “Holistic Approach to Human-Centeredness, Resilience, Sustainability, and the Impact on the Sustainable Development Goals in the Era of Industry 5.0”

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Dresden Model of Adaptability: "Holistic Approach to Human-Centeredness, Resilience, Sustainability, and the Impact on the Sustainable Development Goals in the Era of Industry 5.0"

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Abstract: The pursuit of human-centered, sustainable and resilient production is shaping a future-oriented approach to manufacturing processes in the context of Industry 5.0. How can such production be implemented? For this purpose, this article analyses the effects of the developed Dresden Model of Adaptability (acronym: DreMoWabe) on the integration of holistic sustainability. The focus is on investigating the promotion of economic, environmental and social sustainability goals in terms of the 17 Sustainable Development Goals as well as analysing strategies to increase resilience to changing environmental conditions. A human-centered perspective is considered. The model proves to be a holistic approach that drives sustainable development of the production system through the comprehensive integration of human, technology, and organisational structures.

Keywords: DreMoWabe; Dresden Model of Adaptability; HTO approach; Industry 5.0; transformation capability; transformation; transformational empowerment; sustainability; sustainability goals; Sustainable Development Goals (SDG)

1. Introduction

The future vision of Industry 5.0 was outlined by the European Commission in the paper "Industry 5.0 - Towards a sustainable, human-centric and resilient European industry" [1] in 2021. The focus here is on social goals that go beyond conventional growth and the mere creation and preservation of jobs. In addition to ensuring resilient economic prosperity, production must recognize the limits of planet Earth, in particular the finite nature of resources. At the same time, it is crucial to place the well-being and creativity of employees at the center of production activities [1]. This approach extends the previous idea of Industry 4.0, which primarily focused on the intelligent networking of people, machines and products using information and communication technologies [2]. According to the European Commission, Industry 4.0 with its "Survival of the Fittest" strategy is unsuitable for achieving the goals set in Europe with regard to protecting the climate, overcoming planetary crises and alleviating social tensions [3]. With the 2030 Agenda, which was adopted by the global community in 2015, the United Nations (UN) set out 17 globally agreed Sustainable Development Goals (SDGs). These goals serve to promote socially, economically and environmentally responsible development. The focus is on overcoming global challenges such as poverty and hunger, waste of resources and inequalities [4]. At the halfway point in the implementation of the 2030 Agenda, the recently published SDG progress report [5] presents a sobering result. 50 percent of progress on the sustainability goals is weak and inadequate, while 30 percent is at risk of stagnation or even regression. With regard to goals 8 (Decent Work and Economic Growth) and 12 (Responsible Consumption and Production), for example, the following picture emerges: the multiple crises caused by wars, climate and energy crises and the pandemic are threatening the global economy. Since the coronavirus pandemic, global real gross domestic product

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per capita has only risen marginally on average. Analysts are forecasting only a moderate increase of 1.6% for the current year. This is due to continuing price increases, high interest rates and general uncertainties on the global market. The growth target of 7 percent set as part of the Agenda has so far been missed by a wide margin. Since 1970, global domestic material consumption (DMC), i.e. the amount of raw materials used in the production process, has tripled. In high-income countries, the material footprint per capita is ten times higher than in low-income countries. In order to achieve the goal of efficient and sustainable use of finite resources or resources with different demands, measures must be taken to support the implementation of sustainable practices and to decouple economic growth from resource use [5]. What concrete steps do manufacturing companies in particular need to take in order to be resilient and people-focused while acting in harmony with social, economic and environmentally responsible sustainability principles? In the following study, the positive effects of the Dresden Model of Adaptability (acronym DreMoWabe) - a framework for the description, evaluation and improvement of adaptability (translated from german) [6] - are highlighted. The article analyses the effects of DreMoWabe on the models of sustainability [see [7] and [8]]. Considering the 17 SDGs defined in the 2030 Agenda and their sub-goals, a novel approach is presented to achieve progress in terms of resilience, human-centeredness and sustainability in the sense of Industry 5.0 and the green agenda.

2. Materials and Methods

2.1. Dresden Model of Adaptability and Its Components

The Dresden Model of Adaptability (in German “Dresdner Modell der Wandlungsbefähigung”, acronym: DreMoWabe) was developed to describe, evaluate and increase the holistic adaptability of production companies (see Figure 1). [6] Adaptability is understood as "[...] the structural ability of a (production) system to change beyond the pre-planned [...]" [9, p. 10] and can be achieved through the implementation of transformation enablers. With its three-dimensional structure, DreMoWabe establishes a link between the transformation enablers established in the literature [see [10]], the holistic understanding of the system through the use of the human-technology-organisation approach (HTO) [see [11]] and five design levels identified as essential in the corporate context. Each cell of the DreMoWabe results from the individual combination of transformative properties, HTO dimension and design level. It can be identified with the help of a unique coding (DNA). The code O-mob-C, for example, identifies the cell of the "Organisation" dimension, the transformative property "mobile" in the design level "Company level". In addition, each cell is described by a criterion and the recommendations derived from it. The structure is based in particular on the design principles of Industry 5.0 and places the overarching themes of human-centricity, resilience and sustainability at the centre of the recommendations. [6] Through this combination, the DreMoWabe provides a reference and organisational framework “[…] to enable production companies to describe and evaluate their own adaptability in a model way and [...] to be able to react more quickly to changes in the production environment“ [6, p. 1].

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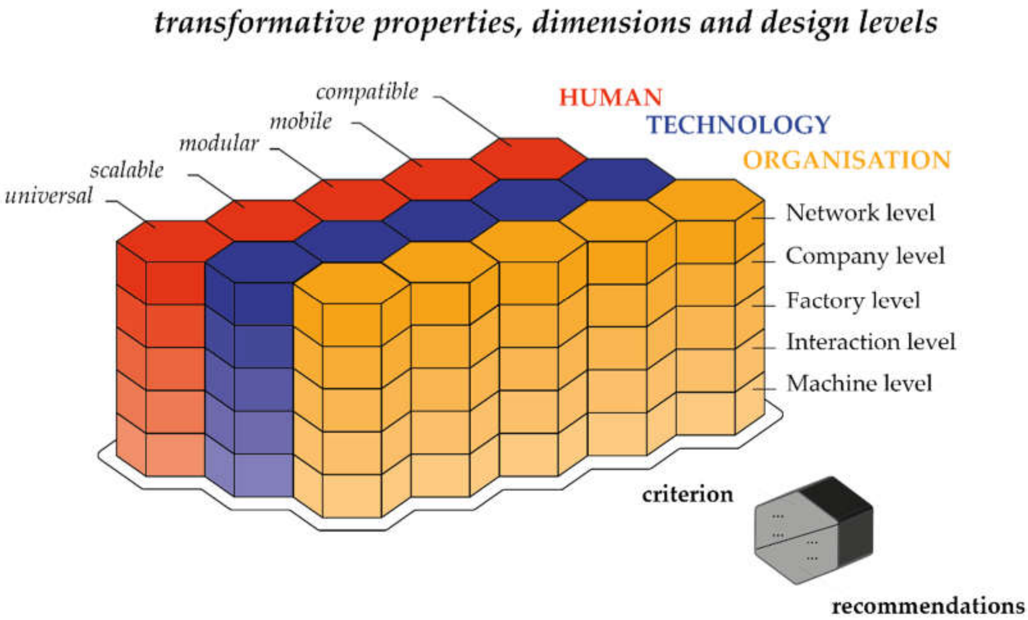

Figure 1. The Dresden Model of Adaptability (DreMoWabe) [6, p. 6.]

2.2. Interdependencies between Adaptability and Resource Protection

The extent to which the implementation of the individual transformative properties has an influence on the sustainability of a company has already been examined in [12]. The focus of the analysis was on possible interactions between increasing the adaptability of a company with the help of enablers and increasing sustainability by considering so-called resource conservation strategies. Resource conservation strategies (r-strategies) are strategies that help to extract, process, transport and ultimately dispose of fewer resources. [13] These include principles such as reparability, durability, upgradability, reusability, energy efficiency, freedom from harmful substances and also the recycling process of products. In its perfection, resource conservation is the consistent circulation of all resources used. To this end, four basic principles of r-strategies were identified as essential in the article: recycle, repair, reuse and reduce. In order to achieve significantly lower resource consumption in production and throughout the entire life cycle, all strategies must focus on reducing the use of resources and waste emissions. Therefore, energy efficiency must also be considered when returning resources and reuse and repair must be given preference over simply recycling. For a holistic approach, resource conservation strategies must also be applied at the complete production system level. It is therefore necessary in every design process - regardless of whether for a single product, a work process or an entire business model - to consider the above-mentioned r-strategies, but above all the reduction of resource use. By combining the four basic resource conservation strategies with the five transformation enablers, it was possible to evaluate the interdependencies between them and already observe positive interactions in the overall systemic implementation of changeability on the use of resources. [12] However, in order to achieve holistic sustainability, further aspects of sustainable management must be considered at all company levels in addition to resource conservation.

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2.3. Assignment of the SDGs to the Overarching Sustainability Aspects

The best indicator of how extensive the concept of sustainability should be considered are the scope of the Sustainable Development Goals (SDGs). With the Agenda 2030, the UN proclaimed 17 SDGs and 169 associated targets in 2015, which are "[...] of crucial importance for humanity and its planet" [14]. In these global SDG, the UN advocated, among other things, creating a world in which technologies take account of climate change, biodiversity is respected, every country enjoys sustained, inclusive and sustainable economic growth, there is decent work for all and consumption and production patterns and the use of all-natural resources are sustainable. [14] They committed themselves to comprehensive and ambitious measures for joint action to achieve sustainable development in its three dimensions - economic, social and environmental - in a balanced and integrated manner. These three dimensions are also used in common sustainability models, such as the three-pillar model of sustainability or the overlapping circles model of sustainability [see [7] and [8]]. Only when all these three dimensions works as a unit a sustainable development is achieved. [8] In Figure 2, the SDGs were allocated to the three dimensions of sustainability based on [15]. However, the allocation of the individual goals depends on the perspective and some cannot be clearly assigned to just one dimension. Based on the overlapping circles model, some objectives were therefore allocated to the intersections of the dimensions. Overall, this also illustrates the interaction and

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interdependencies of the individual sustainability dimensions.

Figure 2. Allocation of the 17 SDGs to the pillars of sustainability [based on [15] [Icons based on [.16]

2.4. Related Work on Sustainability Goals and the Influence of Global Manufacturing

There are currently hardly any publications that propose concrete measures for implementing or achieving the SDGs specifically for companies. The white paper [17]developed jointly by PwC, GMIS and UNIDO is one of the few that highlights the crucial role of governments and companies in implementing the global sustainability goals. Producers and suppliers are obliged to support governments in achieving the SDGs. Companies should focus in particular on goals 7 to 9 and 12 to 13, as this is where they can achieve the greatest possible economic benefits and have the greatest sphere of influence. The white paper presents specific company examples and measures for the goals "Affordable and clean energy", "Decent work and economic growth", "Industry, innovation and infrastructure", "Responsible consumption and production" and "Climate action". It also shows how important the introduction of measures in the company is for the fulfilment of sustainability goals. One example of this is Ford's redesign of an existing industrial plant, which improved several sustainability goals. The modernization of the production line led to the creation of an open and vibrant space in harmony with people and nature, resulting in reduced energy consumption, lower maintenance costs and CO2 offsets. This not only contributes to the fulfilment of SDG 9 (Create resilient infrastructure, promote inclusive and sustainable industrialization and support innovation), but also improves SDG 15 - Life on land by creating a green, living roof that serves as a habitat for various animal species. [17]

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3. Investigation of the Correlation of DreMoWabe to Sustainability Dimensions and Their Goals

3.1. Examples of Use and Possible Combinations of the Model

The following chapter presents the results of the investigation into the influence of DreMoWabe on the sustainability dimensions of social, ecological and economic aspects and their SDGs. This is preceded by an excerpt (see Figure 3) from DreMoWabe, which shows the HTO dimensions with the respective criterion (see Table 1) for each developed design level and each transformative property (compatible, mobile, modular, scalable and universal).

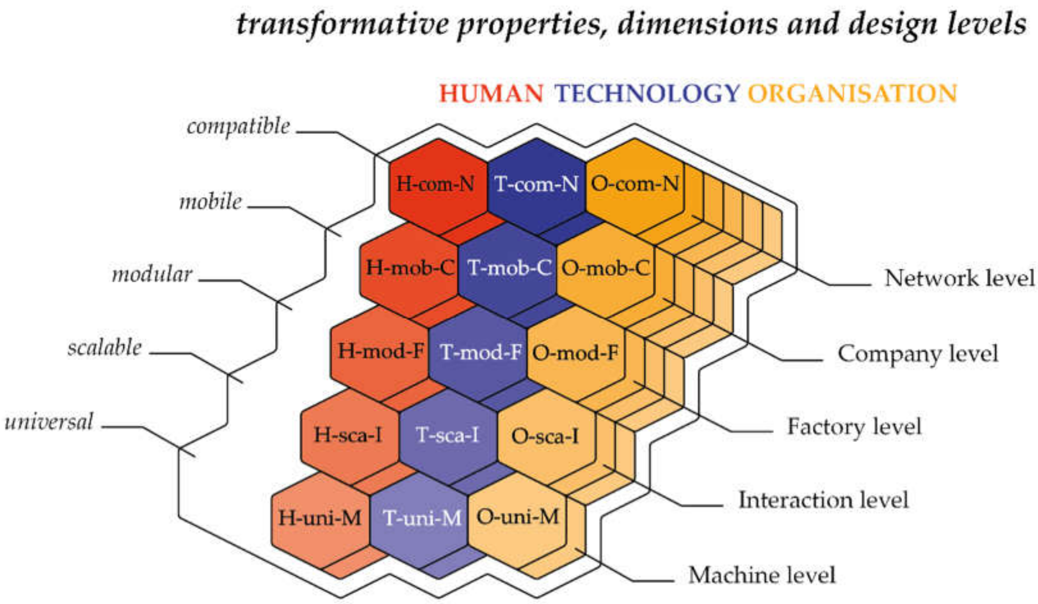

Figure 3. Possible combinations of DreMoWabe [6, p. 8.]

Table 1. Criterion for exemplary combination of transformative property and design level [6, p. 8 ff..]

H-com-N	T-com-N	O-com-N
Adaptability of employees to change work tasks due to the opening and flexibilization of the value chain	Integration capability and networkability of systems, production and assembly stations across company boundaries	Compatibility of corporate goals with those of the value creation network
H-mob-C	**T-mob-C**	**O-mob-C**
Local independence for the completion of work tasks	Local mobility of objects as well as production and assembly assets in industrial production/processing	Local mobility of organizational units
H-mod-F	**T-mod-F**	**O-mod-F**
Allocability of qualification and further training measures for employees	Divisibility and interaction capability of production components	Divisibility and reconfigurability of process flows and the necessary authorizations and qualification requirements
H-sca-I	**T-sca-I**	**O-sca-I**
Expandability or reducibility of the interaction of hybrid	Expandability or reducibility of the interaction of hybrid	Expandability or reducibility of the interaction of hybrid

teams from the employees' perspective	teams in terms of hardware and software	teams from an organizational perspective
H-uni-M	**T-uni-M**	**O-uni-M**
Universal deployability of employees on various machines, modules and systems	Universal applicability of machines and systems for a wide range of work processes	Universal applicability of processes and workflows to production changes

In total, there are 75 combinations that can be described by the unique DNA with the respective criterion.

3.2. Presentation of the Causal Relationship between DreMoWabe and the Sustainability Goals and Their Overarching Dimensions

Due to the large number of possible combinations for examining the positive effects of DreMoWabe on the SDGs, two specific examples are selected on the one hand and an excerpt from other positive effects on the sustainability dimensions on the other. As already illustrated in Figure 2, some SDGs can be assigned to several pillars, as the topic of sustainability is considered in an interdisciplinary and holistic manner. It is important to emphasize that this list does not claim to be exhaustive, but is rather presented in the form of theses, most of which can be supported by previous studies from the literature.

3.2.1. Coding: Human-Mobile-Company Level

Local independence for the completion of work tasks (remote work) can have the following positive effects with regard to the SDGs, and consequently on social, ecological and economic sustainability aspects.

SOCIAL DIMENSION

SDG 3: GOOD HEALTH AND WELL-BEING

Remote work allows employees to work more flexible hours and adapt to personal needs, which leads to an improved work-life balance. It contributes to physical and mental health, and thus to general well-being and performance, especially for employees with a high level of digital competence and a strong technical understanding [18].

SDG 5: GENDER EQUALITY

Remote working can promote gender equality by offering women, especially mothers, the flexibility to combine family and career. [19]

SOCIAL AND ECONOMIC DIMENSION

SDG 4: QUALITY EDUCATION

Remote working may give employees easier access to further education and training opportunities, as they can participate regardless of time and place. This may improve their professional qualifications.

SDG 8: DECENT WORK AND ECONOMIC GROWTH

Remote work enables companies to attract and retain talent globally, contributing to a diversified and highly skilled workforce. This supports economic development in different regions and promises a competitive advantage for the companies concerned. [20]

SDG 10: REDUCED INEQUALITIES

Remote work can help reduce social and regional inequalities by giving people in different geographical areas the opportunity to participate in quality jobs. In addition, it offers people with disabilities the opportunity to participate in working life without the challenges of physical office structures. This can contribute to a more inclusive society. [21]

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ECONOMIC DIMENSION

SDG 9: INDUSTRY, INNOVATION AND INFRASTRUCTURE

Remote working makes companies more resilient and agile in the face of unforeseen events such as crises or changing market conditions. This in turn helps to increase competitiveness.

SDG 17: PARTNERSHIPS FOR THE GOALS

Remote work promotes global partnerships that go beyond traditional teamwork within the company. It promotes innovation by benefiting from a broad range of experience.

ENVIRONMENTAL DIMENSION

SDG 11: SUSTAINABLE CITIES AND COMMUNITIES

Remote working can help to reduce traffic in cities and thus the strain on urban infrastructure caused by commuter traffic. This supports the political course for sustainable urban development. [22]

SDG 13: CLIMATE ACTION

Reducing commuting and business travel and energy consumption for lighting, heating, cooling and operating office equipment in office buildings can lead to lower greenhouse gas emissions and contribute to climate protection. According to a study by researchers at Cornell University and the Microsoft Group, working remotely can reduce greenhouse gas emissions by around 54 percent compared to traditional office work. [23] Although remote working has the potential to reduce the carbon footprint, it is essential to implement a thorough review of commuting patterns for work and private journeys, vehicle ownership and individual building energy consumption. The goal is to fully realize the environmental benefits. [23] Companies can also contribute to environmental sustainability by promoting sustainable working practices and the use of environmentally friendly technologies.

ECONOMIC AND ENVIRONMENTAL DIMENSION

SDG 12: RESPONSIBLE CONSUMPTION AND PRODUCTION

By reducing commuting and office space requirements, remote working can contribute to a more efficient use of resources and thus promote more sustainable consumption and production methods. In addition, the use of information and communication technology leads to a reduction in office and consumable materials.

3.2.2. Coding: Technology-Modular-Factory Level

The transformation enabler modularity in the technology dimension refers to the internal structure of a system consisting of independent, functional units or modules. At the factory design level, this also means that all production components and systems have standardised physical properties, including connections, interfaces and data exchange formats. Ideally, the individual components are arranged in flexible process modules that can be planned, started up and operated independently.[12] It is important to note that the exact impact on the sustainability goals depends on various factors such as the industry, the implementation of modularity and the respective company practices. In the following, it can be shown that the divisibility of production components into modules and their ability to interact with each other have positive effects on economic, ecological and social sustainability and thus on the achievement of the SDGs.

SOCIAL DIMENSION

SDG 3: GOOD HEALTH AND WELL-BEING

The divisibility of production components and standardised data exchange formats promote the technological progress of the production system, as this enables upgrades with improved software or individual modules can be replaced more easily with newer ones. In this way, for example, lower pollutant emissions can be achieved and the health of employees can also be promoted.

SOCIAL AND ECONOMIC DIMENSION

SDG 1: NO POVERTY and SDG 8: DECENT WORK AND ECONOMIC GROWTH

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The modularity of production systems allows companies to react more flexibly to unforeseen events such as crises or changing market requirements. In addition, a modular structure facilitates the recycling of raw materials, which reduces supply risks such as price fluctuations, availability and dependencies and enables a more circular economy. All of this contributes to improving the resilience and competitiveness of companies, leads to sustainable economic growth and the creation and safeguarding of jobs [24].

ECONOMIC DIMENSION

SDG 9: INDUSTRY, INNOVATION AND INFRASTRUCTURE

A modular design of production components facilitates the modernisation and retrofitting of production systems. By replacing or upgrading individual components using clean and environmentally friendly technologies, factories and production processes can be made more efficient and resource-saving. Innovations can be integrated and tested more quickly. This makes it easier to transfer research results to society and accelerate technological progress.

SDG 17: PARTNERSHIPS FOR THE GOALS

The production modules' ability to interact through standardised interfaces promotes innovation and research partnerships between companies, suppliers and other stakeholders in order to jointly achieve sustainable development goals. At the same time, this facilitates equal access to knowledge and technology.

ECONOMIC AND ENVIRONMENTAL DIMENSION

SDG 7: AFFORDABLE AND CLEAN ENERGY

This goal also includes increasing energy efficiency - in this area, progress can be made considerably faster at factory level thanks to more easily replaceable modules and more energy-efficient processes can be implemented.

SDG 12: RESPONSIBLE CONSUMPTION AND PRODUCTION

A modular, flexible design of machines and systems supports simple and efficient use for different tasks. This can sustainably reduce the resources required to operate the systems and adapt them to different production tasks. In addition, the modularity of products promotes the reparability and interchangeability of individual components. This reduces the use of primary raw materials and necessary replacement purchases of entire systems/machines. In addition, dismantling into individual components after the end-of-life of the systems is made possible, thus increasing recyclability and reusability. Modularity implemented at factory level in the form of matrix production systems also supports the efficient production of spare parts and the reproducibility of other products. This also supports responsible consumption by the end user and reduces waste. It is also possible to reconfigure a matrix production system in order to deconstruct products and recover the resources used. [25]

ENVIRONMENTAL DIMENSION

SDG 13: CLIMATE ACTION, SDG 14: LIFE BELOW WATER and SDG 15: LIFE ON LAND

The improved reparability and recyclability of modular systems leads to a reduction in the need for primary raw materials. This reduction in resource consumption and the associated lower environmental impact can protect the climate as well as the ecosystems under water and on land. It also minimises supply risks, particularly for critical raw materials that are needed for technologies that are crucial to climate targets, such as electric motors and batteries. [24] A modular structure of the production system also supports the technical progress of the production facilities and their scalability. This reduces energy consumption and therefore also makes a positive contribution to climate protection.

3.2.3. Summary of Other Positive Interactions

The analysis of the other cells of the DreMoWabe shows further positive effects on the implementation of the SDGs in addition to the examples presented. For example, the adaptability of employees to changing work tasks and methods (**H-com-N**) promotes lifelong learning and professional development, which in turn contributes to improving the qualifications and skills of the workforce (SDG 4). The ability to integrate and network systems, production and assembly stations across company boundaries (**H-com-T**) enables the optimisation of production processes, promotes the development of innovation partnerships (SDG 17) and thus enables the more efficient use of resources. As a result, it helps to reduce the ecological footprint (SDG 13) and promote more sustainable consumption and production practices (SDG 12). The expandability or reducibility of the interaction of hybrid teams from an organisational perspective (**O-sca-I**) can contribute to job satisfaction and the optimal use of employee potential (SDG 8) as well as technology. This promotes innovation processes within the company and production processes can be optimised through the use of advanced technologies such as artificial intelligence, robotics or cyber-physical systems. This leads to a more efficient use of resources and the promotion of sustainable infrastructures. (SDG 9) The universality of machines and systems (**T-uni-M**) in turn enables not only adaptation to different work processes, but also to the ergonomic, individual requirements of individual employees. In this way, more people can be integrated into the labour market, employees can be protected, changes in the market can be responded to more quickly and competitiveness can be increased (SDG 8). It is also possible to process different material cycles, e.g. from materials returned to the production cycle, which reduces the consumption of resources and thus the environmental impact of production (SDG 12, 14 and 15). The example illustrates that there are positive interactions between the implementation of the enablers of transformation in the HTO dimensions and the achievement of the SDGs at all design levels.

4. Critical Consideration of the Effects of DreMoWabe on Sustainability

Like almost every situation in life, event or decision that is made, there are positive and negative aspects, adaptability is no exception. Furthermore, adaptability should not be seen as an end in itself. The desirable goal is not maximum adaptability, but rather the minimum required to achieve it. [6] In addition, the economic aspects of every recommendation or measure must be considered in every company. In terms of improving holistic sustainability, this also means dealing with the potential disadvantages of implementing measures. Only in this way is a company in a position to obtain a comprehensive picture of the impact of individual measures and recommendations from DreMoWabe and to make well-founded decisions based on this. In the context of the discussion on the above recommendation on remote working, its negative effects on social, economic and environmentally responsible goals must also be considered. These can be: Potential isolation of team members due to the increase in asynchronous (e-mail, instant messaging) as opposed to synchronous communication (video (conferencing)) ([26, p. 70] cited in [27, p. 6]), increased individual energy consumption [23, p. 2], the strengthening of traditional division of labor [28, p. 2] and thus conventional role models [29, p. 36] as well as declining productivity in some industries (e.g. call centers [30, p. 2]). The risks associated with the division of production components into modules must be considered in a similar way. Functioning division and interaction capability require a standardized structure as well as uniform data formats and interfaces. However, this can lead to dependencies on individual suppliers and make the introduction of completely new technologies more difficult under certain circumstances. It is therefore particularly important to rely on standardized, generally used interfaces and data formats. On the other hand, it is also important to ensure the universality of the individual modules and, to use new innovation strategies such as open source hardware if it is possible. It is also necessary to actively consider the entire life cycle of products and production components as early as the design and procurement process in order to enable complete cycles of the resources used even after their normal service life. Only through the integration of circular economy principles and the promotion of longevity, reuse and recycling can resource efficiency be achieved permanently and consistently. [31] The same applies to the comprehensive analysis of further transformation-enabling measures and their possible negative

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interactions in relation to the goals of sustainable development. It is important to note that the majority of the disadvantages identified can be mitigated through sensible political and corporate measures on the one hand, and through investment in infrastructure and technologies on the other. To this end, suitable evaluation and monitoring measures must be implemented in companies in order to achieve continuous improvement and adaptation with regard to resilience, sustainability and human-centeredness.

5. Conclusions und Research Outlook

The current level of fulfilment of the 17 SDGs and their comprehensive sub-goals for sustainable development is anything but promising. To put it bluntly - serious. However, the global challenges for economic, social and ecosystems are more present than ever before. For this reason, reliable measures are needed to protect finite resources and improve the economic situation at the same time. It is imperative to break down the stubborn opinion in the economy that there is a conflict of objectives between economic growth and resource consumption. The coronavirus pandemic has also shown "[...] how little resilience many structures around the world have." [32, p. 124] In order to manage these challenges, the Dresden Model of Adaptability (DreMoWabe) was presented in this article and analyses its impact on the implementation of sustainable development in line with the 17 SDGs. The application and mode of action of the model was illustrated using the example of two specific measures. By analysing other cells, it was possible to show how DreMoWabe increases the adaptability of a company and also has a positive impact on the environment. The DreMoWabe as a model for increasing adaptability has already been validated in previous work. Investigating the impact on the SDGs is a theoretical concept that has so far been verified by means of literature research and expert interviews. In order to validate the long-term effectiveness, a comprehensive case study with companies is planned for the future and is currently still pending. This will also make it possible to test the suitability and feasibility of the concept in corporate practice. As every measure can also have negative aspects and only measurable goals can be achieved, it is also necessary to develop an evaluation procedure as part of the case studies. This evaluation procedure should make it possible to quantify the measures implemented by the transformation enablers and their impact on the sustainability goals. These key figures also make the benefits for companies clearer. Only through proactive action and innovative solutions that are also politically supported can a change in thinking be brought about and progress made in line with the Industry 5.0 era and the 2030 Agenda.

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