Time to Change: Considering the 4th Industrial Revolution from Three Sustainability Perspectives

André Ullrich and Norbert Gronau
Department of Business Informatics, University of Potsdam, August Bebel Str. 89, 14489 Potsdam, Germany

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Abstract: Industry 4.0 leads to a radical change that is progressing incrementally. The new information and communication technologies provide many conceivable opportunities for their application in the context of sustainable corporate management. The combination of new digital technologies with the ecological and social goals of companies offers a multitude of unimagined potentials and challenges. Although companies already see the need for action, there was in the past and currently still is a lack of concrete measures that lever the potential of Industry 4.0 for sustainability management. During the course of this position paper we develop six theses (two from each sustainability perspective) against the background of the current situation in research and practice, and policy.

1 INTRODUCTION

Increasing consumption of resources, climate change, inequality of opportunity and income, or precarious working conditions are just a few examples of the many challenges society and companies are facing today. At the same time, however, short term agility and economic sustainability needs always to be ensured. Companies must constantly take into account a multitude of demands, both from internal and external stakeholders, such as customer orientation, decent working conditions, or technological advancements. A supposedly salvific solution for these requirements is applying Industry 4.0 mechanisms and principles.

The 4th industrial revolution (4IR) suggests to apply principles and technologies from the Internet of Things (IoT) on the manufacturing industry. The concept Industry 4.0 was widely disseminated and has received great international attention. However, the hype as a savior for industrial development towards digitalized factories, in which efficient processes and handling of resources or ergonomic working conditions lead to better framework conditions for all affected parties is disillusioning. The 4IR-reality – apart from its promising progress – remains below expectations. One primary point, which is giving rise to concern is that enterprises have no dedicated strategies for developing themselves towards a 4IR capable enterprise. Although it is becoming apparent that companies with an effective 4IR strategy are economically more successful, only 10% posses and follow an 4IR strategy according to a study of 2000 global CXOs (Deloitte, 2020). These respondents furthermore consider climate change and environmental sustainability as the most urgent societal challenge these days.

The concept of sustainability gained worldwide recognition in 1987 with the report "Our Common Future" of the World Commission on Environment and Development also known as the Brundtland Commission. For the first time, compliance with the three pillars of sustainability (economic, environmental, social) was formulated by governments as national goals (Linnenluecke et al., 2010).

The United Nations Environment Programme regards the transformation of industrial production as a ”new economic paradigm – one in which material wealth is not delivered perforce at the expense of growing environmental risks, ecological scarcities and social disparities” (United Nations Environment Programme, 2011). 4IR may offer a huge opportunity to align the goals of a sustainable development with the ongoing digital transformation in industry, which in turn also carries the potential to turn into a threat for society if sustainability targets are not taken into account while implementing Industry 4.0. At the moment, the concept is referring to sustainability

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aspects only in a very limited way (Beier et al., 2020). We argue that research as well as practice and politics need to focus more on how sustainability aspects can gain more influence in 4IR.

From a sustainability perspective, Industry 4.0 lags behind what is possible and societally desirable. Internet of Things, Artificial Intelligence, cloud, or big data analytics are in focus, disproportinately neglected thus far is, however, a holistic – not technology-centred - sustainable consideration of human, technological, and organizational processes and structures. This would according to our understandig present the best lever to future-oriented work and societal cohabitation. Thus, there is a change in focus of action necessary, if the promising potentials of 4IR shall be leveraged. During the course of this position paper we develop six theses (two in each sustainability sphere) against the background of the current situation in research and practice, and policy.

2 ECONOMIC PERSPECTIVE

Following a market-based view of production and consumption, profit, cost savings, economic growth and development are crucial aspects of *economic* sustainability. In this vein, the economic sphere of sustainability refers to the capacity of fostering resource efficiency, thereby enabling an entity to endure on the market over time. A more specific view of economic sustainability claims that "economic sustainability focuses on that portion of the natural resource base that provides physical inputs, both renewable (e.g. forests) and exhaustible (e.g. minerals)" (Goodland, 1995) into the production and application processes. Economic and social sustainability converge when it comes to considering business ethics, workers' rights or fair-trade, whereby all of these aspects can be encountered from research, practice, and policy.

2.1 4IR Is an Imbalanced Number-driven and KPI-based Transformation Process in Which Social and Environmental Goals Are of Secondary Nature

When considering 4IR real world implementation projects it unveils that there is a broad variety of different goals at the beginning of such projects. To name a few target areas we refer to increasing usability and workplace performance, horizontal and vertical integration by connecting entities as well as resource-saving circular economy. In entrepreneurial context, they all have to proof against the priority of economic efficiency. Therefore, 4IR was supposed to result in decrease of production costs by 10-30%, of logistic costs by 10-30%, of quality management costs by 10-20% (cf. Bauernhansl et al., 2017; Table 1). Thus, a general pro of 4IR is that it enables lower manufacturing and service cost by better resource allocation and usage. Profit orientation and entrepreneurial responsibility are not mutually exclusive. Responsible business practices need to be part of a companies' strategy, since companies rely on a well-functioning environment and vice versa.

Table 1: Economic potentials of Industry 4.0 (Bauernhansl et al., 2017).

Costs	Effects	Potentials
Inventory costs	• Reduction of safety stocks • Avoidance of Bullwhip and Burbidge effect	-30 – 40%
production costs	• Improving of OEE • Process control loops • Improvement of personnel flexibility • Use of Smart Wearables	-10 – 30%
Logistics costs	• Increasing the degree of automation • Smart Wearables	-10 – 30%
Complexity costs	• Line spans extension • Trouble shooting reduction	-60 – 70%
Quality costs	• Everything as a Service (XaaS) • Real-time quality control loops	-10 – 20 %
Maintenance costs	• optimization of spare parts inventories • Condition-oriented maintenance • Dynamic prioritizations	- 20 – 30 %

Although digital process control allows to expect a more efficient use of raw materials, energy and water, the corresponding potential for saving resources is not fully exhausted, since cost savings would change motivational structures and affect the production as well as the consumption behavior (Foit, 2018): Decreasing unit costs imply that recycling is less profitable, that is the positive effects of transparency are not realized. Furthermore, they provide a strong incentive for increasing the production output. The resulting additional resource consumption is usually higher than the initial savings. On the consumer side influences a potentially lower price – if passed through by the producing company – usage behavior such as fostering a disposable culture. From an economic point of view, this disposable culture is a prerequisite of contemporary market economy and would enable an increase in sales volumes. Even if contemporary economic and financial systems and, thus, companies, politics as well as society rely on growth, resources are limited and therefore precious. This growth is based to a great extent on resource exploitation. Besides the above discussed efficiency gains the focus needs to be broadened on effectiveness of transformation process and measures too.

Within such top-down-driven transformation processes, usually changes are made that address positively the KPIs of a company. Of course, figures are in primary focus of management since they allow for a holistic diagnosis and steering of the company. These figures usually inform about production, purchase, sales states, that is they are of economic nature. Environmental figures and reports gaining more importance since millennium. Eco Management and Audit Scheme (EMAS) as new environmental policy instrument assesses the environmental impact of a company to improve its sustainable development. Its application is rather self-motivated and participation of companies is still expandable. The international environmental management norm ISO 14001 emphasizes a continuous improvement process regarding environmental performance of a company and addresses rather external demands. Thus we see that there is a tendency towards entrepreneurial responsibility regarding environment and employees. However, 4IR initiatives and transformation projects need to incorporate environmental effects and employees need to be more integrated into their projects. Focusing the employees, this might ultimately lead to declining personnel absence costs and less health-care costs, when they, e.g., can actively participate in transformation processes by co-design work processes and tasks. Additionally, the consideration of environmental goals, e.g., by incorporating and compensating negative external costs would allow for intergenerational justice.

2.2 IT Artifacts Are Not Sufficiently Sustainable Themselves and, Thus, Itself Rather a Cost Driver than a Sustainability Realizer

In the literature on sustainability, technologies and IT artefacts are characterized as instruments for achieving sustainable development (cf. Orr et al., 2014; Stuermer et al., 2017). Stuermer et al. (2017) argue that digital artifacts should be regarded as corporate resources that shall be designed according to sustainability characteristics. However, short-term cost-efficiency was often the primary overarching paradigm when designing new technologies. Instead characteristics like longevity, reusability, or up- or recyclability, and sustainable design principles like scalability, modularity, reconfigurability, or redundancy should be orientation-points when designing and creating sustainable information technologies.

The life-cycle of a technology as a whole needs to be considered when designing as well as when purchasing a technology. Nowadays, besides interoperability and connectivity aspects, far too often the initial acquisition and maintenance costs are focally considered when companies acquire new technologies. Furthermore, the cost and insecurities regarding longevity and long-term applicability are especially for SMEs a barrier. Over the last years it could be observed that they either delay purchasing new technologies or acquire new technologies such as sensors, actors, or assistant devices that still have to proof their additional value for the manifold specific use cases yet, in order to realize potentials of digitization and not simply do digitization. The environment is unnecessarily burdened by technological and electronical waste that is frequently hardly further processable and, thus, requires monetary expenses for special waste disposal. Additionally, effectiveness gains are not used, since new technologies have to be acquired when replacing a prevalent technology due to lacking interoperability with other technologies or systems.

Accepting such kind of shortcomings is a relatively high price for gaining short-term efficiency, which, of course, is necessary to secure survivability of a company. In the long run, however, IT artifacts are rather a cost driver, as they have been designed and realized thus far. IT artifacts are means to achieve sustainability (which besides energy efficiency gains they do not) but are itself not sustainable, that is, they do not sufficiently lever economic potentials that lie in their longevity, adaptability, and reusability yet.

3 ENVIRONMENTAL PERSPECTIVE

The *environmental* sphere of sustainability primarily affects the usage of natural resources, whereby not only the consumption is considered but also the residuals and waste that possibly result from using technologies. In this light, pollution prevention includes natural resources such as air, water, land and waste. Therefore, environmental sustainability addresses both production and consumption (Lozano and Huizingh, 2011).

3.1 4IR Makes No Significant Contributions to Environmental Sustainability besides Energy Efficiency Gains Thus Far

Probably inter alia because energy efficiency gains have been one of the initial goals of 4IR, efficiency seems to be the most important topic with regard to environmental sustainability. Colloquial argumentation is that 4IR allows to avoid the unnecessary usage of resources the customer does not need or want. This is achieved by realizing mass production advantages when producing in batch size one numbers. It is widely advertised as innovative revolution, that will radically change the way of production by having a holistic perspective on resource usage and value creation. However, the goals of Industry 4.0 still follow very traditional pathways. Modern digital technologies are incorporated into traditional production environments. Cyber-physical-system-enhanced machines are getting interconnected and reach a certain level of autonomy.

The often mentioned term resource efficiency presumably points towards environmental effects and implications of Industry 4.0. Xu et al. (2018) supported the efficiency claims with empirical evidence, where a company achieved a reduction in energy consumption by 10% through the application of IoT technology and, thus, realized the prophesied cost reductions. Economic and social aspects are the dominating dimensions within the Industry 4.0 literature (Beier et al., 2020): The majority of the prevalent literature on Industry 4.0 refers to economic issues (Table 2) promising either generally more efficiency or only concretizing the statement to more efficiency in production (cf. Xu, 2018; Zhong, 2017). Many articles claim improved resource efficiency as a consequence of Industry 4.0. It is not made clear though under which circumstances those efficiency gains are to be expected. A detailed contribution of Industry 4.0 to a green growth of society is also missing.

According to green growth theory, economic expansion is compatible with the earth's ecology by using natural resources in a sustainable manner. Technological change and substitution shall enable decoupling of GDP growth from resource usage and carbon emissions. Empirical evidence does not support green growth theory (Hickel and Kallis, 2020). Material productivity, however, positively influences the decoupling of GDP and resource usage, which is not surprising since resource efficiency is a usual target characteristic of modern manufacturing processes. The overall resource consumption though is increasing much more than efficient 4IR production processes can compensate yet.

Table 2: Number of sustainability related text fragments per category and dimension in most cited Industry 4.0 literature (cf. Beier et al., 2020).

	Economic	Environmental	Social
Human	35	15	88
Technology	99	44	64
Organization	111	52	68
Overall	140	63	93

The vision of Industry 4.0 as it is contemporarily perceived stands rather for a digital update of the established patterns of industrial production than a disruptive concept with transformative potential. This is especially harmful when it comes to integrating sustainability aspects in industrial processes. Industry 4.0 seems to sustain the path dependencies of a traditional instead of initiating a sustainable industrialization. The contribution to environmental sustainability is quite limited to energy efficiency gains thus far.

3.2 The Amount of Technological Waste Will Increase Massively in the Midterm Range and This Will Lead to a Very Negative Ecological Balance

The number of internet capable devices as well as the amount of generated data already exceeds by far the number of humans living on planet earth. The phenomenon of mobile phones that are replaced by new models - even when they are fully functional - due to a few new features is a considerable indicator for development in industrial environments, when politics or industry associations do not intervene.

4IR applications have in sum a much higher energy consumption and demand for miniaturized computers. This demand cannot always be covered by sustainable sources and thus consumes resources and produces thereby waste materials with which society has to deal with in the long run.

Due to lacking interoperability between systems and yet not institutionalized standards some extend of technologies, be it sensors or other kind of technology enabling Industry 4.0 principles, are replaced even before their life-cycle is over. Furthermore, the additionally needed minicomputers are hard to recycle, e.g., the dismantling process in which acids are necessary to detach the gold from circuit boards. Hence, it can be assumed that the negative ecological effects of this industrial technologization overweigh by far the above mentioned energy efficiency gains. Therefore, the reintegration of waste products (resources, partial and end products) into the value-added cycle is elementary in order to operate profitably against the background of rising resource prices, conflict raw materials and increasing use of rare materials (e.g. in chip production).

On the contrary, These minicomputers are more and more adaptable to the current requirements through their software. The hardware could remain the same, since they are now sufficiently powerful and flexible enough for most application scenarios. Accordingly, it may also be conceivable that waste production due to increasing replacement is not a primary issue, if the hardware is sufficient. Much more problematic is the extreme increase in IoT devices mentioned at the beginning of this article, which may lead to a shortage of raw materials.

Improvements with regard to decomposing and recycling are thus far not neither sufficiently considered nor investigated by research. The few that take up this issue follow the colloquial assumption that 4IR allows higher revenues and contribution margins. These statements are justified due to the fact that products and services can be better adjusted to individual customer needs and apart from mass production higher prices can be called for them. The future external costs of technologies are yet not fully incorporated into prices and technological advancements are from this perspective made at the expense of an ecological balance.

4 SOCIAL PERSPECTIVE

The social sphere of sustainability deals with crucial aspects such as the standard of living and work, education and community supporting opportunities, including in terms of equity and equality. Aspects addressing human and work are in particular focus in this sustainability perspective. Environmental justice as well as stewardship of natural resources both locally and globally link social sustainability to the environment. However, as Goodland (1995) highlights, social and environmental sustainability are connected in a quite more fundamental way, since "environmental sustainability or maintenance of life-support systems is a prerequisite for social sustainability".

4.1 4IR Requires a Much Higher Level of Qualification from Workers - Further Qualification Still Is a Neglected Area in Enterprises, Especially SMEs

On the one hand, the digital transformation opens up new perspectives for employees. New occupational fields, reorientation or even the elimination of monotonous activities can be mentioned as examples. On the other hand, the resulting automation of work tasks and processes means above all a reduction in labor costs through rationalization. However, this does not necessarily and universally has to be accompanied by losses on the employee side. So far, automation has replaced a few activities, but at the same time it has also increased the demand for new activities and thus labor in general (cf. Arntz et al., 2020). The ability to carry out physical tasks in an unstructured work environment is solely one capability amongst others that is yet and will in near future not (be) automated. However, current studies (cf. Bakhshi et al., 2017; Tabares, 2019) draw a more differentiated picture. While the newly emerging needs are primarily in the areas of mechanical engineering and IT services, job losses are mainly concentrated in production and administration. Thus, there is an imbalance expected.

Process automation and robots are an important factor in meeting the predicted future shortage on the labor market (Jacobs et al., 2017). However, it is to be expected that the requirements on the demand side of the labor market will change more quickly than the supply side will be able to answer with skills development. Technology skills or competences in the facets of, e.g., process, organization, interaction are gaining more importance in manufacturing (Gronau et al., 2017). Vocational training measures need to follow suit by adapting the focus of training measures towards the new requirements as well as experimenting with learning approaches such as life-long-learning, learning on or near the job. Furthermore, vocational training is still mostly done through frontal teaching, which is based on the behavioristic stimulus-response model or related concepts that assume a causality between teaching and learning. This understanding is proven to be outdated (cf. Teichmann et al., 2019) due to understanding of internal cognitive human processes as well as the advantages of haptic experimenting with new technologies, especially when they are the object in question as it is in this industrial technologization.

This, by technology induced transformation, leads to new roles or even activity types such as, *inter alia*, the system regulator or the IT specialist for digital networking. Requirements they are facing are, amongst others, due to a high level of interdisciplinarity, the sharing of experiences about products, materials, and work across processes, divisions, and hierarchies or context transferability. They have to organize themselves and other process participants in this new environment. Therefore, an understanding of the process structures is required. Furthermore, employees have to be capable of problem solving, supervision, judgement, holistic thinking, and need to possess an ability of communication and adaptability (Prinz et al., 2016; Bakhshi et al., 2017).

At the moment, the requirements towards the employees are increasing radically. Not just regarding their professional qualification but also due to changes of work in general. Especially SME cannot provide sufficient capacity for further qualification for which employees need to conduct qualification seminars, away from their work processes. Therefore, a long and near the job qualification measures seem promising to enable employees that are faced with new forms of work and company organisation, new work content and new forms of employment. In addition, work design will be more strongly influenced by entrepreneurial forms of labour supply. In particular, however, workers will have to cope with the fact that the processes will be much more diverse and flexible than they were in the past. In addition, required basic skills referred to as digital literacy are still not a common capability of the employees, especially in the manufacturing halls. Against this background, further qualification is an underrepresented area in companies, especially in SMEs.

4.2 Individual Needs of the Employees within 4IR Transformation Projects Are Not Sufficiently Considered

Besides the required qualification, the employees need also to be open for the upcoming transformation. This can be achieved by raising awareness and influencing their attitude positively. Acceptance is a positive attitude towards technologies and the intention to use the technology for the intended purpose. This is achieved by eliminating barriers and applying participation measures (Figure 1). The transformation usually is an iterative development process that is characterized by insecurities or uncertainties regarding development paths and the envisaged target state on side of the employees.

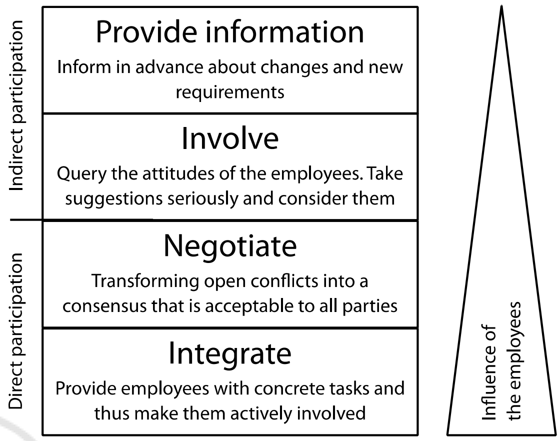

Figure 1: Levels of employee participation.

Within these development processes new technologies, processes, and work tasks for the employees require an accompanying change management that focusses on the employee needs. In e.g. individual interviews or workshops the general sentiment can be gathered and afterwards measures for sensitization be developed. Especially isolated pilot test cases are widely used in manufacturing for demonstrating the benefits of new technologies such as AR glasses. Often, however, these technologies require usability optimization, since ergonomic handling was not necessarily in focus when designing. Additionally, technologically induced limits due to, e.g., battery volume and weight can be stressful over time for the employees.

Learning human-machine interfaces and augmented reality systems turn employees into augmented operators. This closes competence gaps, accelerates processes and reduces errors. At the same time, requirement, communication and instruction structures are changing and, in the long term, the entire corporate culture is changing: there is a shift from physical to predominantly psychological demands and thus stress at work. Although time and location flexibility can promote work-life balance, it is also associated with a mixture of work and private life, which leads to stress.

Furthermore, changes are exhausting for most people. Repeated familiarization with different technologies is cognitively effortful, especially when there are unused potentials regarding their usability. Therefore, the transformation accompanying change management measures are necessary in order to sensitize the employees and to minimize cognitive barriers are a still underemphasized aspect of transformation projects.

In Industry 4.0 literature the employees are addressed quite often. However, concrete implications for future work and job profiles are still mainly imprecise and vague (Beier et al., 2020). Therefore, framework conditions need to be set by policy and companies for context sensitive adequate qualification measures. This is inter alia done by developing of a comprehensive road map for this digital corporate transformation, comprising development path and transition states under consideration of socio-technical change approaches. Furthermore, strategies are required in the mid-term range to protect the individual needs, that is e.g. acceptance, satisfaction, and health of employees.

5 CONCLUSION

Industry 4.0 leads to a radical change that is progressing incrementally. The new information and communication technologies provide many conceivable opportunities for their application in the context of sustainable corporate management. The combination of new digital technologies with the ecological and social goals of companies offers a multitude of unimagined potentials and challenges. Although companies already see the need for action, there was in the past and currently still is a lack of concrete measures that lever the potential of Industry 4.0 for sustainability management.

Economic potentials provided by Industry 4.0 are not sufficiently made use of thus far. Technologies for realizing these potential seem to have also a negative economic effect at the moment. They are mostly cost intensive when purchasing and - since they are conceived as means for realizing sustainability rather than they are sustainably designed themselves – they promise to be a cost driver in the long run.

The environmental sphere is often limited to residual energy efficiency with supposed rebound effects. Here it is important to adopt a holistic, systemic perspective of resource conservation. Furthermore, the target criteria of a sustainable society are often only considered in isolation when examining Industry 4.0 in general or individual technologies, so-called IT artefacts in specific. Long term effects of technological waste of products that are produced and used at the moment for realizing Industry 4.0 are still under-researched. Here we need concepts and regulations for re or upcycling of technologies realizing Industry 4.0 at the moment but also for products and goods in general. Following the route of a circular economy and approaches of bio-economy seems to be a promising first step for practice.

As stated earlier, new technologies lead to new processes and this, in turn, leads to new tasks for the employees. Ultimately, humans are in the center of Industry 4.0 transformation processes. Success and failure strongly depend on how usability, ergonomics, and, of course, acceptance of changing technologies, processes, roles and new tasks can be secured. Furthermore, systematic qualification and sensitization measures need to be developed and applied from the companies but also supported by political initiatives, e.g., by setting funding schemes and subventions especially for small and medium sized companies.

Industry 4.0 has a high sustainability potential due to intelligent digital technologies, through regionalization or decentralization processes and the optimization of product and resource flows. At the same time, possible rebound effects as well as risks with regard to competition or labor market need to be taken into account. Therefore, incentives from politics should to be set.

Future focus should lie on the questions of how the concept of Industry 4.0 and its concrete implementation can contribute (1) to the realization of the United Nations sustainability development goals or (2) to sustainability aspects beyond energy efficiency and working conditions. In summary, research in the context of Industry 4.0 has, thus far, failed to prove its benefits for a more sustainable production and, therefore, societal development. Practice projects, on the other side, rely to a great extent on the preliminary work of research and are thus increasing efficiency but are mostly not characterized by a sufficient effectiveness for realizing green and sustainable manufacturing. It, however, is not to late and a way need and will be figured, which changes the course of research and practice. Therefore, it is promising that sovereignty, interoperability and sustainability are the future strategic fields of action for Industry 4.0, created by policy makers, with the goal of shaping digital ecosystems globally. Therefore, it is time to responsibility and proactively contribute to a more sustainable development of Industry 4.0 and thus a more sustainable society.

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