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More Sustainability in Industry through Industrial Internet of Things?

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Abstract: Industrial production plays an important role for achieving a green economy and the sustainable development goals. Therefore, the nascent transformation of industrial production due to digitalization into a so-called Industrial Internet of Things (IIoT) is of great interest from a sustainable development point of view. This paper discusses how the environmental dimension of a sustainable development can potentially benefit from the IIoT—focusing especially on three topics: resource efficiency, sustainable energy and transparency. It presents a state of the art literature analysis of IIoT-enabled approaches addressing the three environmental topics. This analysis is compared with the findings of a survey among Chinese industrial companies, investigating the sustainability-related expectations of participants coming along with the implementation of IIoT solutions. China has been chosen as a case study because it brings together a strong industrial sector, ambitious plans regarding industrial digitalization and a high relevance and need for more sustainability. The survey was conducted with the means of a questionnaire which was distributed via email and used for direct on-site interviews. It focused on large and medium sized companies mainly from Liaoning Province and had a sample size of 109 participants.

Keywords: Industrial Internet of Things (IIoT); Industrie 4.0; digitalization; sustainability; study; China

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1. Introduction

The global sustainable development policies for the coming decade have been influenced by two major negotiation outcomes: the "Green Economy Concept" and the "Sustainable Development Goals". In 2012, the United Nations Conference on Sustainable Development agreed on policies supporting a green economy, shortly defined as "a low-carbon, resource efficient, and socially inclusive" economy [1]. The conference initiated also the second important outcome—the 2030 agenda for sustainable development was adopted in 2015 encompassing 17 sustainable development goals (SDGs) and defining the direction and aims of sustainable development.

Industry is one of the key sectors in implementing a green economy and the SDGs, for the latter especially SDG 9, aiming at "Building a resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" as well as SDG 12 claiming to "Ensure sustainable consumption and production patterns" [2].

Against this background, the nascent transformation of industrial production due to digitalization is of great interest from a sustainable development point of view. The Industrial Internet of Things (IIoT) is characterized by the fusion of the physical world of industrial production with the digital world of information technology—creating a digitalized and interconnected industrial production. This enables the exchange of live data between machines and product components allowing for a continuous monitoring and steering of relevant production processes. Thus, industrial production becomes much more flexible and transparent.

Research and policies concerning the IIoT have so far mainly focused on economic benefits and ways of supporting the implementation of IIoT in companies and different branches as well as on technical aspects like finding solutions for standardization or data security. At present, only a few scientific projects and studies deal with the implication of the IIoT for sustainable development but recently the linkages between digitalization and sustainability are attracting more and more attention.

In this paper, we will discuss how a sustainable development can potentially benefit from the industrial transformation through digitalization—focusing especially on the environmental dimension. The paper starts with a state of the art analysis of approaches addressing this topic. The following sections provide an overview over the characteristics and findings of a survey in China.

We chose China as a case study mainly for two reasons. Firstly, China has a very strong industrial sector: according to the China statistical yearbook the industrial sector (excluding construction) accounted for 36.3% of Gross Domestic Product [3]. With the "Made in China 2025" strategy released in 2015, the Chinese government has expressed strong interest in strengthening China's manufacturing sector. The digitalization of manufacturing is hereby seen as a key factor for success [4]. Secondly, China, as the most highly populated country with high energy consumption and resulting emissions, plays an important part in fighting climate change and fulfill the "1.5-degree-target" agreed on in the 2015 Paris United Nations Framework Convention on Climate Change. Industrial facilities were responsible for 69.4% of overall energy consumption in 2014 [5]. In the same year, 65.6% of all energy was derived from coal being the main energy source [6]. Industrial coal burning is the dominant contributor to $PM_{2.5}$ as a study shows [7]. In 2014, 72 out of 113 surveyed key cities in China exceeded the annual air quality standards for particulate matter set by the WHO by factor 6 or higher ($PM_{2.5\ annual}$ = 10 $\mu g/m^3$) [8]. Particulate matter is associated with cardiovascular and respiratory diseases and cancer—even at levels below the WHO limit [9]. China suffers severely from this air pollution and has a strong motivation to mitigate these negative environmental impacts. This was recently illustrated by the temporarily or permanent shutdown of thousands of factories in order to control the compliance with emission restrictions [10].

This paper deals with the question of how the environmental dimension of a sustainable development can potentially benefit from a digitalized industrial production. Based on our own previous research [11], three environmental topics were identified as promising to benefit from IIoT: resource efficiency, sustainable energy, and transparency.

2. State of the Art

2.1. Transparency

This paragraph explains why transparency is considered to be a prerequisite for a more sustainable development of industry. Firstly, full transparency along the value chain allows for informed environmental management, for example when reducing the greenhouse gas emission of a product while at the same time avoiding increasing the emission elsewhere in the supply chain. Secondly, reporting on environmental management can positively contribute to the corporate reputation and thus create incentives for other companies to implement environmental management systems themselves. This is only the case when the disclosed information is perceived as credible by the relevant stakeholders. Greenwashing or in the worst case false statements can on the other hand create a reputational risk for companies as recently demonstrated by the Volkswagen scandal [12].

One main feature of the IIoT is the availability of data or information about the production process and production components throughout the entire value chain. This creates transparency and has thus the potential to contribute to an improved environmental management and environmental reporting of companies.

There is not much literature on transparency for sustainability through the IIoT. Different research articles address the potential connection between big data and environmental performance. Keeso (2015) examines possible links between big data and environmental sustainability on a general level asking different organizations such as environmental NGOs, governments or companies how they engage with big data. For companies, he suggests that corporate social responsibility efforts could potentially benefit from big data availability, for example through improved performance measurement, supporting a "[. . .] sense of ownership of sustainability initiatives" [13]. With a more technical focus Song et al. give a review of the "latest advances in environmental management based on big data technologies". Examples for the usage of big data for environmental management summarized by the authors include the information of consumers about environment-friendly products through network platforms and the direct feedback of the consumers' choice. Ideally, this leads to incentives for other companies to improve the environmental quality of their products as well as public participation in environmental management through data sharing and the use of big data to create an "environmental supply chain" for industries. The authors conclude that environmental management can benefit from big data analysis but the theory and method of environmental performance evaluation with big data needs significant improvement [14].

2.2. Resource Efficiency

Improving resource efficiency in producing companies is not new to research. In 2010, Jayal et al. demanded to strive for more sustainability in manufacturing through a more holistic view across multiple product life-cycles with the help of improved models, metrics for sustainability evaluation, and optimization techniques at the product, process, and system levels [15]. Duflou et al. agree that resource efficiency approaches should address multiple levels [16], ranging from technological improvements on the tool machine level [17] through to the restructuring of manufacturing sequences [18], factory layouts and entire value creation networks in the case of globally operating enterprises [16]. Rohn et al. present a review of these resource efficiency technologies and strategies [19].

An often mentioned example for a digital, resource efficient technology is 3D-printing. 3D-printed fuel nozzles have enabled General Electric's LEAP engine to reduce the number of sub-parts from eighteen to only one. This improved the durability of components and reduced its weight by 25%, but also enabled a better optimized geometry to achieve higher combustion efficiency, leading to fuel savings throughout the life of the engine and reducing its CO_2 emissions [20]. 3D-printing and other Additive Manufacturing technologies can be very resource efficient for specific manufacturing applications, such as prototypes, products with small lots and high variances or when making long transportation obsolete (e.g., when printing spare parts for airplanes instead of flying them in). However, it should be noted that there are several open questions regarding the maximum achievable throughput rate in mass production as well as rebound effects especially when used in a private consumer context.

IIoT technologies also offer potentials for end of life processes [21] or smart maintenance services (e.g., [22,23]), and the availability of digital customer information can help to reduce overproduction. However, there are very few scientific studies evaluating these resource efficiency potentials for industry. The Global e-Sustainability Initiative estimates that efficiency gains through digital production will allow for saving 81 billion liter of water and 4.2 billion MWh electricity [24], but parts of this study are heavily disputed in the scientific community [25].

2.3. Sustainable Energy

The IIoT also offers opportunities to strengthen the role of sustainable energy in industrial production. In this paper, the term sustainable energy subsumes both improvements with regards to energy efficiency as well as the enhancement of renewable energy. The following paragraphs will present approaches of how IIoT technologies can be used to save energy and to combine digitized and interconnected factories with renewable energy systems.

Energy can be saved, e.g., by optimizing or replacing specific (non-)digital technologies with digital more energy efficient alternatives, by applying new software solutions that offer energy optimization functionality, or by improving business processes based on the additional data generated in digitized factories. Thirty percent of the total energy consumption by machine tools is consumed while they are in stand-by mode [26]. Fysikopoulos et al. have taken up this challenge and developed a generalized approach to manufacturing energy efficiency based on a machine-level study [27], while Brizzi et al. present a case study on the remote monitoring of robot energy consumption, demonstrating the capability of intelligent applications for managing manufacturing processes [28]. An impressive example for more energy efficiency based on process optimization is presented in [29,30], where an algorithm is introduced that allows reducing energy consumption for industrial robots up to 30% by adapting acceleration and deceleration behavior, without substituting hardware or negative consequences on the production rate.

A more IT-based concept is the energy simulation of manufacturing systems. Thiede et al. argue that environmentally related aspects are currently not sufficiently considered as standard functions in manufacturing system simulation tools [31]. One potential solution approach is presented by Herrmann et al. where a flexible energy flow-oriented manufacturing system was simulated [32]. Similarly, Zhao et al. analyze the sustainability impact of manufacturing by introducing a new information model for product lifecycle management that integrates an energy simulation framework [33]. A more general approach also aiming at energy efficiency in manufacturing is the methodology for planning and operating energy-efficient production systems [34]. Likewise, Caggiano et al. propose a multi-purpose digital simulation approach dealing with sustainable manufacturing systems design through Discrete Event Simulation and 3D digital human modeling. This allowed in a demonstration case from the aerospace industry for a very significant reduction of energy consumption as well as an increase in energy efficiency [35]. A review by Garwood et al. details modeling approaches and discusses the simulation tools that allow for combining Building Energy Modeling and Manufacturing Process Simulation into a holistic approach [36].

IIoT technologies also contain the potential to increase the share of renewable energy consumed in industrial production. At the same time, they can help to reduce the volatility of renewable energy systems either: (a) by flexibly adapting their energy consumption; or (b) by storing or releasing energy (with the help of Power-to-X procedures) depending on the current availability of renewable energy in the market. A prerequisite for all these approaches is to integrate digitized factories as active players into the energy system to immediately detect and communicate the availability of energy in the system and to select and steer the flexible industrial loads.

One way of achieving this integration is making use of so called Virtual Power Plants. Virtual Power Plants are heterogeneous coalitions of distributed energy resources, generally composed of intermittent renewable sources, storage systems, flexible loads, and small conventional power plants that need to negotiate some bilateral contracts in advance prior to participating in the day-ahead market [37]. Digitalized industrial processes are often steered with Cyber Physical Energy Systems (CPES), allowing for a greater temporal flexibility of these processes [38]. Companies that do not produce with maximum load all the time can act as flexible loads, by using the CPES-enabled temporal flexibility to increase their production when a surplus of renewable energy is in the system and reduce it accordingly in case of an energy shortage. Using this flexibility can help enable and strengthen the so-called Demand Side Management (DSM). Bornschlegl et al. present an approach to increase energy efficiency through the use of cyber-physical systems (thereby supporting DSM): reducing the base load especially during unproductive periods in the production flow and selectively switching off temporarily unnecessary components to increase overall efficiency [38]. A complementary approach improving planning processes in energy management is presented in Schmidt et al. with their methodology for the reliable prediction of energy consumption of arbitrary manufacturing processes based on measurements and existing knowledge [39].

In regions where energy infrastructure is a challenge, IIoT technologies can be used, to set up so called mini-grids. The International Renewable Energy Agency (IRENA) defines mini-grids as a system of distributed energy sources, interconnected loads and storage appliances integrating an energy infrastructure, which can operate in parallel with the main grid, off-grid or in islanding mode [40].

Blockchain technology could be a potential digital solution to ease the contracting between energy producers and consumers in such flexible mini-grids [41]. If they help to substitute the combustion of fossil fuels through renewable energy, mini-grids can be an important and sustainable energy technology in some less developed parts of the worlds [42].

In summary, it must be stated that there is rather little research on the overall sustainability impacts of IIoT technologies to date, due to the relative novelty of the concept itself. However, there are some promising approaches, but if their application will lead to a reduced ecological impact also depends on the magnitude of their resulting rebound effects.

The following two sections present the findings of a survey in China, in which we have asked participants about the expected potentials for a sustainable industrial development through digitalization. The aim of this survey is to understand how the theoretical concepts presented in this Stat of the Art Section are actually perceived in industrial praxis.

3. Survey Characteristics

The digitalization of industrial production is still a relatively new concept which is subsumed under different terms. Apart from the term Industrial Internet of Things that is used in this article, it is also known as Industrie 4.0 or Smart Manufacturing. For the survey, we used the more descriptive term "digitalization and interconnectedness" to avoid confusion and also provided a brief explanation of the key characteristics of IIoT based on the definition by Kagermann et al. [43]. The questions mainly covered the environmental and social dimension of sustainability. Based on a literature review a set of indicators were identified which were either frequently mentioned in the context of digitalization and sustainability or seemed especially relevant to the authors for a future sustainable production. The indicators material and energy efficiency, own renewable energy capacities and environmental strategy/standards were chosen to represent the environmental dimension. This paper presents the results linked to the three environmental topics transparency, material efficiency and sustainable energy.

The survey was conducted in three steps between November 2015 and January 2016:

1. The questionnaire was initially developed in English and then translated into Chinese by the local partners from the Institute of Applied Ecology (Chinese Academy of Sciences, Shenyang, China). For a pretest, the questionnaire was discussed with some potential interviewees and slightly revised based on their feedback and comments. To verify the translation, the Chinese questionnaire was re-translated again into German by a native Chinese Speaker, who is not involved in the project.
2. The distribution of the 120 questionnaires was carried out via email and through on-site visits including direct interviews. Additionally, the distribution was supported by the local government. All of the 120 sent out questionnaires were returned; most were sent back via email (47) or were collected from the local governments (40), while 22 were collected on site.
3. Finally, the collected responses were aggregated and documented. Of the 120 questionnaires that were sent out, 11 were returned incomplete, leading to a sample of 109 complete questionnaires. The sample focused on medium to large sized companies. Most are located in Liaoning Province (typical industrial zone located in northeastern China) with 102 returned questionnaires; seven questionnaires were collected from Jiangsu Province and Gansu Province. Fifty-six percent of the companies involved in the survey have more than 250 but less than 1000 employees, 22% employ between 1000 and 2500 people, 6% fewer than 5000 but more than 2500 people and 16% more than 5000 people. The main branches represented in the sample are machine and plant engineering (24%), automotive (22%), information and communication technologies (17%), electronics (15%) and aerospace (12%). Participants in the survey are mainly male (73.4%) and work in the two engineering domains: development (34%) and manufacturing (66%). The sample choice (regional focus, focus on medium and large size companies) was based on the experience

and networks of our Chinese partners to increase the probability for good availability and relevance of partners.

4. Survey Results

To better understand the status quo of the IIoT in China, participants were questioned about their familiarity with the concept of digitalization and interconnectedness, and their vision regarding the pace of development as well as measures of their companies to support digitalization.

Most of the participants are very familiar or familiar with the concept of digitalization and interconnectedness: a fifth of the participants (20.2%) describe themselves as very familiar with the concept, another 52.3% as familiar. Regarding the time horizon of the digital transformation the majority of participants estimates that a moderate shift towards a more digitalized industry will only happen within the next decade (51.4%), while 17.4% expect moderate changes already within the next three years and another 1.8% even within the next year. Nevertheless, Chinese companies seem to start preparing for the digital transformation: 41.3% of the participants stated that their companies have a company-wide strategy dealing with "Digitalization and Interconnectedness".

4.1. Transparency

The sustainability strategy and management in companies could benefit from more transparency based on the IIoT and the generated (big) data. To estimate this potential, we asked participants if their respective company has already implemented an environmental or sustainability strategy and operates an environmental management system. According to participants, more than half of the companies have an environmental or sustainability strategy (53.2%, see Figure 1a) and operate an environmental management system (53.7%). Additionally, the vast majority of participants (84.5%, N = 58) whose companies have implemented a sustainability strategy believe that this strategy will be influenced by digitalization (see Figure 1b).

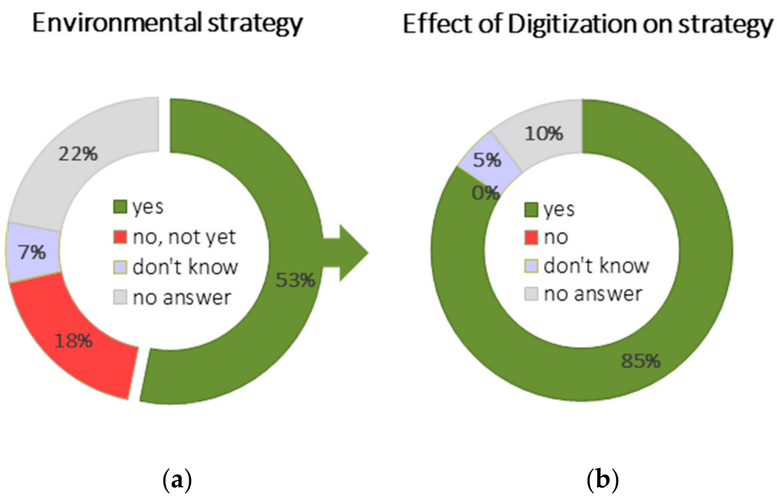

Figure 1. Companies having implemented an environmental strategy (**a**); and share from those, who expect digitalization to affect the respective environmental strategy (**b**).

Moreover, another result of the survey underlines a potential benefit of more transparency: when asked if employees who plan the production process are aware of the amount of energy machines consume, only 14.7% confirmed such an awareness, while 39.4% stated that employees only have a vague idea of the consumption, and another 23.9% of the participants stated that employees are not aware of the energy consumption at all.

To support a more sustainable production in industry, transparency is needed along the whole supply chain to avoid (environmental) problem shifting. This would mean digitally connecting and exchanging data with suppliers along the value chain. Participants seem to be hesitant regarding the involvement of suppliers: 56.9% reject the idea of a future digitalized and interconnected form of collaboration with suppliers to exchange data on design, logistics, ordering and accounting, while only 22.0% think such a digital involvement of supplier will occur in their companies.

4.2. Resource Efficiency

Participants associate rather high expectations regarding improvements in resource efficiency with the application of IIoT technologies in industrial production. Overall, 88.1% of participants expected very high or high material saving potentials, while 83.5% foresee very high or high energy savings due to IIoT technologies (see Figure 2). Apparently, rebound effects do not seem to play a significant role in the perception of the participants.

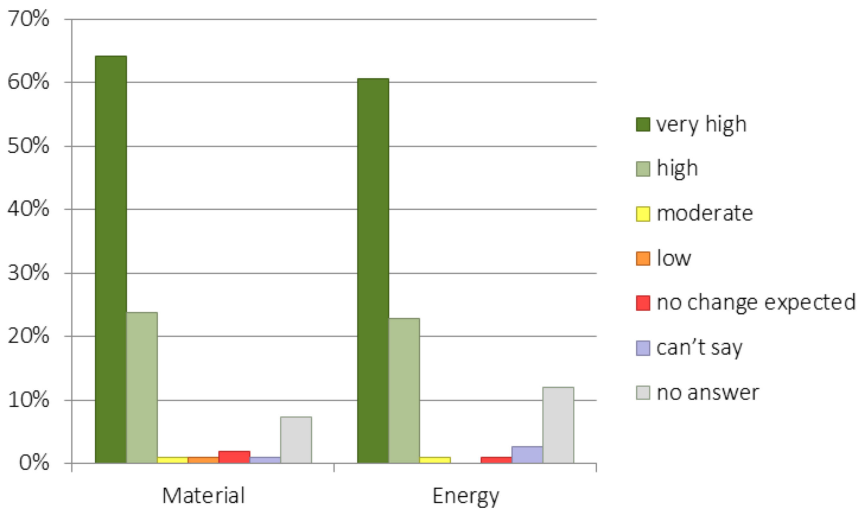

Figure 2. Expected saving potentials.

4.3. Sustainable Energy

In the State of the Art Section, we have discussed some of the synergetic potentials of IIoT technologies and renewable energy systems. In 2015, China had a share of around 8.5% of its total energy supply covered by renewable energy sources [44]. However, only 1.8% of the companies participating in our study have already installed their own facilities for renewable energy generation, while 2.8% were confirming plans to set up their own facilities for generating renewable energy in the next five years. In total, 11.9% of companies already have set up energy storage facilities.

The study also investigated plans of companies to make use of the flexibility to temporarily switch or postpone production processes which will be enabled through IIoT technologies. The majority (59.6%) of participants could not answer whether their company was considering to change production times if that meant, for example, lower energy costs. In total, 34.1% of those participants giving an answer (absolute: 13.8%) are in favor of such a strategy: 40% of which even to a larger extent with more than 5% of their volume of production. Despite this mainly unclear prospect of taking advantage of the IIoT enabled flexibility in production, there is some potential for this strategy as far as production and stand-by times are concerned. Only 1.8% of participants say the machines in their factory do not go into stand-by mode at all, while 8.3% declare their machines spend 2.1–4 h and another 28.4% even more than 8 h in stand-by mode (for detailed numbers, see Figure 3). A similar pattern is obtained when asked how many hours a day the respective company was engaged in production. Here, the vast majority of companies are in production between 9 and 16 h (79.8%) or even shorter hours (10.1%). Judging from these numbers, it can be concluded that there is quite a significant potential to flexibly adjust production processes according to the availability of renewable energy.

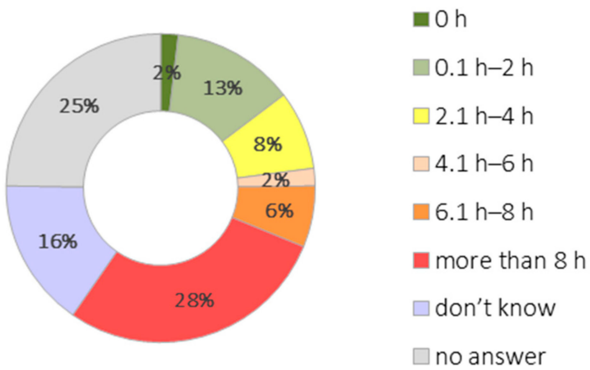

Figure 3. Hours that machines are in stand-by mode per day.

5. Discussion

Transformations in emerging countries such as China play an important role for sustainable development, considering the potential global impacts of these countries. This development must be evaluated for all three dimensions of sustainability. For the social dimension, Beier et al. (2017) provide first insights [45]. For the environmental dimension, three possible starting points for a more sustainable industrial production through digitalization were identified. Our case study supports the idea of potential benefits in these three areas: transparency, resource efficiency and sustainable energy.

The majority of participating companies have a sustainability strategy in place and operate an environmental management system. Almost all participants expect this strategy to be influenced by digitalization. On the one hand, this result suggests a willingness to improve transparency for environmental matters, while, on the other hand, participants seem to perceive digitalization and sustainability not as isolated but interconnected developments. This is noteworthy, since the results of a similar case study conducted in Germany showed a comparable share of participants whose companies have implemented a sustainability strategy (57%, N = 70) but a much smaller share of participants believes that industrial digitalization will have an impact on the sustainability strategy of their respective company (53%, N = 39) [11].

The lack of actual information is one barrier for an effective environmental management. Results of our survey indicate that often relevant people are not provided with environment-related information, as the lack of awareness regarding energy consumption by employees who plan the production processes illustrates. The IIoT-enabled availability of live data on environmental indicators such as energy consumption could make it easier for all employees to access such information and thus effectively improve the environmental management of companies. The supply chain is an important part of an integrative sustainability management, since shifting the environmental burden to suppliers should be avoided. However, our results show that participants are still hesitant regarding the digital inclusion of suppliers. Since this integration is a crucial factor for full transparency, barriers such as security concerns must be identified and solved to exploit the sustainability potentials.

The expectations regarding a more resource-efficient production through digital technologies are high among Chinese participants. They correspond with expectations of other experts in the industrialized world, for example in Germany [45], albeit Chinese participants seem to be particularly optimistic. Improving resource efficiency in one production step does not necessarily lead to a more sustainable production. Further research has to be carried out to identify the framework conditions that assure resource efficiency along the whole supply chain and avoid rebound effects. Additionally, these potentials should be quantified thoroughly.

When interpreting the results of our survey, several facts have to be considered. According to the Renewable Energy Statistics provided by IRENA, China was generating almost a quarter of all global renewable energy in 2015—more than any other country or continent (see [46]). On the other hand, China's energy consumption is so huge that the share of renewable energy is still relatively small:

around 8.5% [44]. Around 81% of the Chinese renewable energy generated stems from hydropower [46], which also means that decentralized renewable energy systems are currently playing a less prominent role. Our survey results emphasize that conclusion: companies which have already installed their own facilities for renewable energy generation, or have plans to do so, are still the rare exception. Digitalization opens new possibilities of integrating renewable energy in the energy systems for example by using the flexibility in industrial production in response to fluctuating renewable energy availability as described above. Given that neither decentralized renewable energy systems nor digital production are a common phenomenon in China yet, it is not surprising that most participants do not feel entitled to answer the according question. Under this premise, it is remarkable that those who gave an answer are clearly in favor of connecting renewable energy with flexible production. Moreover, our results indicate a potential for flexible production based on the statements regarding stand-by times of machines and production hours. Again, this result does not allow an assessment of how realistic the scenario of flexible production is, but hints to a sustainability potential which should be examined further. Taking into account the political pressure on companies in China to reduce their emissions, digitalization could create a window of opportunity for synergies between renewable energy and an IIoT-enabled digitized industry.

The study has limitations due to its relatively small and homogeneous sample, providing only one case study. Survey results are based on the personal opinions and expectations of the participants and therefore do not allow for definitive conclusions about the effects of digitalization. It should also be noted that the digital development of industry is still at its very beginning, and ideas of the concept and implementation are still vague. While 72.5% of the participants describe themselves at least as familiar with the concept, 22% stated that they are not very familiar with this concept. This is reflected in some of the questions where a relatively high share of participants chose the "no answer" option and must be taken into account when interpreting the results. The survey only points out some interesting tendencies regarding the potential synergies of a sustainable development and digitalization in industry. This paper has thus the intention to provide a starting point for the scientific discourse on the linkages of a digitalized industry and a sustainable development. Further research is needed to quantify expected potentials and identify framework conditions to exploit it. It should also be noted that the presented survey was conducted before the "Made in China 2025"—strategy was implemented and it would be interesting to see how this "political push" has influenced the application of the IIoT in China.

6. Conclusions

In this paper, we examined possible benefits through the Industrial Internet of Things for a sustainable development especially with regard to the environmental dimension. Based on a literature review and the research results, we discussed transparency, resource efficiency and sustainable energy as three possible starting points for linking digitalization and a sustainable development of industries. The case study of China provides a first impression on how far the IIoT has already entered into industrial reality. Although a relatively high share of companies already operates an environmental management system (53.2%) and thus demonstrates a certain willingness to improve production environmentally, a lack of transparency regarding their respective impact still exists: only 14.7% of the participants are aware of the amount of energy the machines they operate consume. Both results support our hypothesis that an improved transparency provided by the IIoT-enabled digitalization along the supply chain could lead to a better environmental management of companies. However, this will only be the case if suppliers are included in the digital networks, which seems unlikely, according to 56.9% of the participants. These barriers and concerns regarding the digital inclusion of suppliers have to be addressed. Expectations relating to improved resource efficiency are high (88.1% expect very high or high material saving potentials, 83.5% foresee very high or high energy savings), but further research has to focus on assessing real potentials taking possible rebound effects into account. Although only 2.8% of the participants confirmed plans of their respective companies to set up their own facilities for generating renewable energy in the next five years and the idea of using the flexibility of production seems to be rather new to the participants (59.6% did not answer the question), we think that digitalization and the resulting flexibility of production could create a window of opportunity to support sustainable energy in China. Results have to be interpreted carefully because the study also revealed an occasionally vague vision of the digital development which could change over time. The validity of the study is also limited because of the relatively small sample (109 participants from medium to large size companies, including branches: machine and plant engineering, automotive, information and communication technologies, electronics and aerospace) and regional focus. Nonetheless, this paper should be seen as providing a good starting point for further discussions identifying future research questions.

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Author Contributions: All authors conceived and designed the questionnaire for the study; Bing Xue organized the interviews with Chinese companies gathering the data for the study; and Grischa Beier and Silke Niehoff analyzed the data and wrote the paper.

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