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Digital transformation and environmental sustainability in industry: Putting expectations in Asian and African policies into perspective

Stefanie Kunkel*, Marcel Matthess

Institute for Advanced Sustainability Studies e.V. (IASS), Berliner Straße 130, Potsdam, 14467, Germany

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ABSTRACT

With the increasing use of information and communication technologies (ICTs) in industrial production, the risks and opportunities of these technologies for environmental sustainability as well as political awareness about these risks and opportunities become increasingly important. In this paper we analysed digital and industrial policies of four Sub-Saharan African countries (South Africa, Rwanda, Kenya, Nigeria) and three East Asian and Pacific countries (China, Thailand, Philippines) regarding their expectations about the impacts of ICTs in industry for environmental sustainability. We built on existing frameworks for the assessment of ICTs that distinguish between direct environmental effects which occur during the lifecycle of ICTs and indirect environmental effects which result from the application of ICTs in a variety of production processes and economic activities. We used qualitative content analysis to explore and analyse policy expectations regarding both direct and indirect environmental impacts of ICTs in industry. Our analysis showed that policies express a broad range of vague expectations focusing more on positive indirect impacts of the use of ICTs, e.g. for enhanced energy efficiency and resource management, than on negative direct impacts of ICTs, e.g. electricity consumption of ICTs. Moreover, expectations differed between countries and there was no shared theme that emerged in all policies. We suggest that policies must go beyond awareness of selected opportunities towards the integration of a more systemic understanding of interlinked direct and indirect impacts and pursue targeted measures to employ ICTs as tools for environmentally sustainable industries.

1. Introduction

Industrial production has significant environmental implications worldwide. The industrial sector accounted for 36 % of global total final energy consumption and 24 % of global CO_2 emissions in 2014 (IEA, 2017b). While *energy efficiency* of production is improving in many areas, the overall environmental burden presented by industrial production is assumed to grow (UNIDO, 2017b). With accelerating digital transformation in industry, i.e. the increasing development and application of information and communication technologies (ICTs) in manufacturing and service industries (IEA, 2017a; WBGU, 2019), science and society discuss the role of ICTs for environmentally sustainable industrial development (Banga and te Velde, 2018; Global e-Sustainability Initiative (GeSI), 2020; World Bank, 2016).

A broad body of scientific literature on the implications of the digital transformation for economy, society and the environment has emerged since the 1990s (Berkhout and Hertin, 2001; ITU, 2019, 2013; Mansell and Wehn, 1998), although less so for environmental sustainability implications of ICTs in developing countries (Heeks, 2014). Empirical evidence regarding the environmental risks and opportunities of the digital transformation is mixed and often points to uncertainties regarding the net environmental effects of the digital transformation (Beier et al., 2020).

Despite these uncertainties, a widening range of purposes and goals have been ascribed to the digital transformation in industry varying across national policies. Although still scarce, policy analyses have shown that numerous political endeavours of low- and middle-income countries (LMIC)[1] revolve around the idea of ICTs leading to socio-economic development and economic growth (Friederici et al., 2017). For instance, the relevance of the digital transformation in embedding local industrial production in global value chains is being discussed (Africa Growth Initiative, 2018). With regards to the relationship between environmental sustainability and ICTs, Fritzsche et al. (2018) find that there is an emerging discourse of intergovernmental organisations (IGOs) on the role of ICTs for environmentally sustainable industrial production. Notably, they hold that research has yet to

* Corresponding author.
E-mail addresses: stefanie.kunkel@iass-potsdam.de (S. Kunkel), marcel.matthess@iass-potsdam.de (M. Matthess).

[1] We use the term “low- and middle-income countries” interchangeably with the term “developing countries”.

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investigate how national institutions address this topic (Fritzsche et al., 2018).

Against this backdrop we pose the following research question: What are developing countries' policy makers' expectations about the role of ICTs in industry for environmental sustainability? Using qualitative content analysis, we analyse expectations regarding the role of ICTs in industry for environmental sustainability in national industrial and digital policies of four Sub-Saharan African countries (South Africa, Kenya, Rwanda, Nigeria) and three East Asian and Pacific countries (China, Thailand, Philippines). We develop a framework to categorise the expectations regarding environmental effects of ICTs which we found in the analysed policy documents. We highlight five examples of these expectations, discussing in the respective country contexts the envisioned goals that are portrayed in the policies.

The aim of this paper is to deepen our understanding of how policy makers in LMIC portray the relationship between ICTs, industrial development and environmental sustainability. This is important for various reasons: Firstly, policies play an important part in shaping industrial and technological development (Palvia et al., 2015) and there are often gaps between the design of the use of ICTs within policies and actual conditions on the ground (McBride and Stahl, 2010). Analysing policy makers' expectations can help bridging the gap between currently isolated debates of technology-centred research on the one hand and policy making on the other hand (Fritzsche et al., 2018). Secondly, policy analysis may serve as an early warning system for path dependencies related to the proliferation of ICTs. For instance, it may unveil technologies as carriers of shifting political and corporate interests in evolving socio-technical systems (Cordella and Iannacci, 2010). Thirdly, policy analysis can reveal specific sustainability challenges of policy makers in LMIC. With digital and industrial policy making still at an early stage, LMIC policy makers face the challenge of simultaneously balancing growth of incomes, environmental and social concerns in order to deliver win-win-win solutions (UNIDO, 2017a). Analysing how far these goals are already reflected in policies might give impulses at the intersection of policy making for sustainable digital and industrial development.

2. Framework: environmental effects of ICTs in industry

For our application in the industrial context we adapted existing frameworks by Beier et al. (2018), Berkhout and Hertin (2001) and Erdmann et al. (2004) which categorise the environmental effects of ICTs. As further elaborated in the methodology section, the framework is used in our content analysis as an analytical lens to structure and interpret policy expectations.

We broadly distinguished between the main categories of direct environmental effects and indirect environmental effects of ICTs. Direct environmental effects are impacts associated with the lifecycle of ICTs (Berkhout and Hertin, 2001). Indirect environmental effects result from the application of ICTs in other goods and services. Although earlier studies have already investigated potential indirect environmental effects of ICTs in different contexts (Erdmann et al., 2004), we deemed it necessary to account for rapid technological advancements in recent years and consider the corresponding scientific insights regarding their impacts. Moreover, we regarded the application of a framework with an emphasis on the industrial context as particularly fitting for our analysis.

Within the category of indirect effects, Beier et al. (2018) highlight three sub-categories where the application of ICTs in industry can be linked to environmental risks and opportunities: resource efficiency, sustainable energy and transparency. Furthermore, we subsume systemic effects of the use of ICTs, e. g. rebound effects (Erdmann et al., 2004), under the main category of indirect effects. The effect categories are summarised in Fig. 1.

In the results section we illustrate the two suggested effect categories with five examples. These examples emerged as particularly noteworthy and suitable for further analysis from the content analysis because a) a tangible issue related to ICTs (e.g. e-waste, energy) was expected to be b) targeted by a specific solution (e.g. regulation). The examples are summarised in Table 1.

2.1. Direct environmental effects of ICTs

Direct environmental effects are impacts of resource and energy use along the lifecycle of ICTs, i. e. production, use and disposal of ICTs. With respect to resource use in production, ICTs for large-scale use in industry will require increasing amounts of materials in their production. A study commissioned by the German Resource Agency, for instance, expects the demand for critical materials, such as lithium, dysprosium/terbium and rhenium, used for emerging technologies, many of which are related to the use of ICTs in industry, to exceed production of these materials (2013 levels) two times by 2035 (Marscheider-Weidemann et al., 2016).

With respect to energy use of ICTs, while electronic components like sensors and controllers become smaller and more energy-efficient, the number of digital components increases in a digitalised industry. Moreover, the underlying infrastructure (such as data centres, servers, networking gear, power and cooling equipment) requires a growing amount of electricity. In a study on the estimated use-stage electricity demand by 2030, Andrae and Edler (2015) find that ICTs might, in the worst case scenario, use up to 51 % of global electricity and be responsible for 23 % of global greenhouse gas emissions.

With respect to the disposal of ICTs, e-waste accumulation is an increasingly important issue, particularly in low- and middle-income countries. While global annual e-waste was estimated to stand at 45 million tonnes in 2016, a projected 52 million tonnes will be generated in 2021 (Baldé et al., 2017).[2] Although 95 % of the useful materials from a computer could potentially be recycled (Robinson, 2009), the decreasing size of devices makes it more difficult to recycle rare materials (Hilty, 2011). In 2016, 80 % (35,8 Mt) of global e-waste was not recycled, 4 % were disposed as residual waste, whilst the remaining 76 % remained untracked (Baldé et al., 2017). Most of untracked e-waste is exported from high to low- and middle-income countries and disposed in landfills, or else burned and dissolved in acids (Heeks et al., 2015; Nnorom and Osibanjo, 2008; Robinson, 2009).

2.2. Indirect environmental effects of ICTs

Indirect environmental effects result from the application of ICTs in other goods and services, e.g. digital data unveiling resource waste or recycling potential in a production process. With respect to resource efficiency in industrial production, ICTs have been discussed as enablers to reduce resource use in different contexts (Gu et al., 2013; Jayal et al., 2010; Song et al., 2018), for instance through additive manufacturing. Additive manufacturing (AM) enables the creation of three-dimensional objects applying material layer-by-layer on the basis of a digital plan of the object (Gebler et al., 2014). AM has the potential to improve resource efficiency and enable lifecycle management (Ford and Despeisse, 2016). The use of "Recycle Bots" to recycle polyethylene for the production of 3-D printing filament, for instance, has been shown to result in a reduction of recycling-related energy consumption of up to 70 % (Kreiger et al., 2014). Gebler et al. (2014) see a potential of reduced CO_2 emissions through AM considering the emission-intensity per unit of output. However, Birkel et al. (2019) point to the danger of increasing waste production. High customisation might lead to difficulties in reducing, reusing, recycling and reselling products.

With respect to transparency, more granular and real-time data are

[2] While not all e-waste is generated by ICT devices (also refrigerators, TVs, etc.) the contribution of ICT devices to e-waste is fuelled by increasing numbers of, among others, mobile devices (GSMA, 2017).

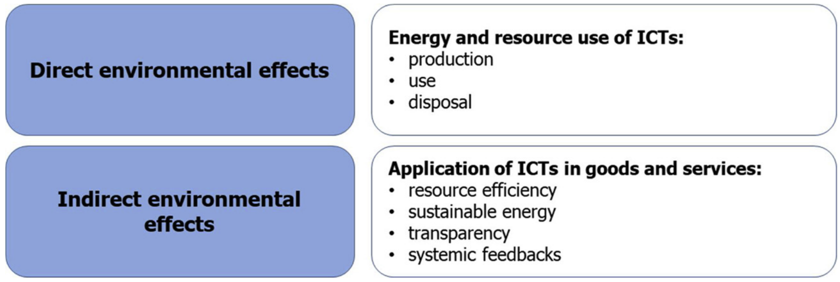

Fig. 1. Effect categories of environmental effects of ICTs in industry, adapted from Beier et al. (2018), Berkhout and Hertin (2001) and Erdmann et al. (2004).

Table 1
Examples of policy expectations and their corresponding effect categories.

Effect category	No.	Example	Focus countries	page
Direct environmental effects	1	E-waste and legal frame	Kenya, Nigeria and Rwanda	5
	2	Green ICT	Thailand, Philippines, Nigeria and Rwanda	6
Indirect environmental	3	3D print in the aerospace industry	South Africa	7
	4	Renewable energy proliferation	Rwanda, Kenya and China	7
	5	Digital monitoring of resource use	China	7

important requisites for more sustainable industrial production processes (Beier et al., 2018). The environmental impacts of products and services occur at different points along the life cycle in different geographical locations. Increasing transparency by collecting and consolidating data from geographically dispersed value chains gathered at all stages of the product (and service) life cycle can enhance sustainability management within and across firms. For instance, real time data flows from machine-to-machine communication and electronic product tags could facilitate the implementation of the “circular economy” concept with the aim of creating vertically integrated and cross-industry networks with closed material loops (Sousa Jabbour et al., 2018; Tseng et al., 2018).

With respect to sustainable energy, some studies argue that the use of ICTs opens possibilities for integrating renewable energy into the energy mix for industrial production, for instance through smart grids (Amin and Wollenberg, 2005). On the supply side, consumers can be integrated in the provision of electricity by photovoltaic (PV) panels, making them "prosumers" (Grijalva and Tariq, 2011). On the demand side, fluctuating renewable energy flows could be matched more easily with flexible industrial production scheduling and industrial orchestration, i.e. the process of optimised energy production and use through more granular data and simulation methods to control manufacturing processes in accordance with energy availability (Beier et al., 2018; Ding et al., 2017; Weinert et al., 2011). For example, virtual power plants can help to visualise and manage the energy capacities fed into and taken from the grid by various energy sources and energy consumers (Pudjianto et al., 2007).

Additionally, ICTs have systemic effects on production and consumption patterns, as well as individual behaviour, attitudes, values and governance processes. Firstly, ICTs are assumed to increase productivity and thus accelerate economic growth (Farhadi et al., 2012). Empirical studies come to varying results about the extent of the productivity effect (Hawash and Lang, 2019; Pieri et al., 2018). Secondly, ICTs have been discussed in the context of achieving the decoupling of economic growth from resource or energy use through efficiency increases, and to arrive at a less material-intensive economy (Berkhout and Hertin, 2004; Erdmann et al., 2004; Hilty, 2008). Increases in (energy) efficiency, however, tend to be counteracted by systemic feedback effects, also called "rebound effects": If the ICT-related economic growth rate in an industrial sector exceeds the increase in energy or material efficiency enabled by ICTs in this sector (decoupling rate), efficiency gains through ICTs are overcompensated and total resource use increases (Hilty et al., 2011; Polimeni et al., 2015; Pothen and Schymura, 2015). However, in a simulation study of how energy demand would develop without ICT-driven energy efficiency improvements, the authors argue that efficiency gains induced by ICTs compared to a scenario without ICTs can lead to decreases in energy use in some domains such as in the freight transport sector (Achachlouei and Hilty, 2015).

3. Methodology

3.1. Country and policy document selection

Given our interest in the digital transformation in industry and its relation to environmental sustainability, we assumed that digital and industrial policy documents would yield relevant policy expectations. Consequently, we scanned the websites of authorities on the highest administrative level for these documents in our focussed regions, Sub-Saharan Africa and East Asia and Pacific. We excluded informal reports such as blogs, surveys or workshop reports. Moreover, we excluded publications with too narrow thematic scopes regarding our research question, such as cybersecurity strategies. Our specific search terms are summarised in Table 2.

We screened the remaining policies from 27 countries, a total of 38 policies, to gather preliminary insights regarding the degree to which these documents provide information relevant to our research question. We discarded documents that did not include passages and chapters on the environmental effects of ICTs in industry. Consequently, 25 policies from 21 countries were discarded. A list of excluded documents is

Table 2
Search terms for policy documents.

	Digital policy	Industrial policy
Search terms	ICT development plan, ICT policy/strategy, digital(-isation) policy/strategy, digitalisation and economic development policy/strategy	industrial development policy/strategy, industrial transformation programme, industrial(-isation) policy/strategy, industrial(-isation) programme, industrial(-isation) plan

Fig. 2. Document selection process.

provided in Appendix A. The remaining 13 policies from seven countries fell under the scope of our research topic and were thus selected for the qualitative content analysis. These documents were not restricted to single topics, but instead covered the cross-cutting issues of digital transformation, industrial development and environmental sustainability that we aim to investigate. The country selection process is summarised in Fig. 2. A list of the selected documents can be found in Table 3.

3.2. *Qualitative content analysis*

For the analysis of the policy documents, we chose qualitative content analysis (Schreier, 2015). The goal of qualitative content analysis is to get a condensed description of a phenomenon, building on a set of categories to describe it (Elo and Kyngäs, 2008), which in our case are the policy expectations regarding the environmental effects of ICTs in industry. We used the software MAXQDA to conduct the qualitative content analysis. In the first step, we read the selected policy documents in detail and identified general themes and subthemes. We assigned an initial category to each new aspect relevant to our research question, for instance the category “renewable energy”.

In the second step, we analysed the coded text passages through the lens of our framework for environmental effects of ICTs in industry (Section 2). We assigned coded text passages to the sub-categories within the main categories of both direct and indirect effects. For instance, if policies mentioned the potential contribution of ICTs to energy efficient production, the text passage was assigned to the sub-category "resource efficiency" (indirect environmental effects). We deliberately chose not to start the reading and analysis through the lens of our framework in the first step in order ensure that we captured the entirety of relevant text passages. However, we found that only few expectations could not be grouped into one of the sub-categories which we had identified ex ante. These were grouped in the category “Miscellaneous”.

In the third step, we compiled and paraphrased the categorised text passages for each country in two tables differentiating for instance between accounts of current circumstances and perceived issues on the one hand and future goals to tackle these issues on the other hand. This enabled us to identify “blind spots” (i.e. effect categories for which no expectations could be found). We additionally provided five examples for expectations on direct and indirect environmental effects of ICTs.

4. Results & discussion

4.1. *Expectations about direct environmental effects of ICTs*

Table 4 lists the sum of expectations on direct environmental effects of ICTs that were expressed in the digital and / or industrial policy of the respective country. Where applicable, we assigned the expectations to the fitting phase of the lifecycle (i.e. the sub-categories) that they referred to, indicated by the grey boxes in each row. All other expectations were grouped into the sub-category "Miscellaneous". Policy expectations are abbreviated in the corresponding column in Table 4. A longer version of the paraphrased text passage from the policies is provided in Appendix B.

The results highlight that all countries referred to direct effects of ICTs within their respective policies. Especially the end of the lifecycle of ICT products received attention (e.g. e-waste). In general, direct environmental effects of ICTs as well as anticipated goals are hardly quantified. Hence, policy expectations appear in the form of generic goals, but they often fail to elaborate what constitutes the concrete environmental problem of ICTs in the country’s context.

4.1.1. *Example 1: e-waste and legal frame*

The policies of Kenya, Nigeria and Rwanda emphasise the respective country’s need for an improved legal framework and regulations for ICTs’ related environmental impact, particularly addressing the disposal of ICT devices. The proposed measure is relevant not only in the light of e-waste that is being imported into these countries (Heeks et al., 2015), but also given the fact that e-waste production is beginning to grow within the region of Sub-Saharan Africa (Baldé et al., 2017). Although not explicitly addressed in the policies we analysed, similar trends and concerns can also be perceived in other countries. China, having itself become the largest producer of e-waste in the world with a large and flourishing informal e-waste market (Orlins and Guan, 2016), banned foreign e-waste imports from 1 January 2018 (Fu et al., 2018).

Reflecting upon what has happened since the publication of the policies until our analysis in 2019, all three Sub-Saharan African countries have either drafted (Kenya, Nigeria) or published (Rwanda) national e-waste management policies. For instance, in Kenya the National Environment Management Authority (NEMA) drafted the “Environmental Management and Co-ordination (E-waste Management)” regulations 2013 (NEMA, 2013). However, it is also important to strengthen concerted efforts on the national level to

Table 3
Selected policy documents.

No.	Country	Name of the document	Type of document	Year of publication	Author
1	China	*"Guiding Opinions of the State Council on Actively Propelling the Internet Plus"*	Digital policy	2015	State Council of the People's Republic of China
2	China	*"Made in China 2025"*	Industrial policy	2015	State Council of the People's Republic of China
3	Philippines	*"The Philippine Digital Strategy Transformation 2.0: Digitally empowered Nation"*	Digital policy	2014	Commission on Information and Communications Technology
4	Thailand	*"Executive Summary Thailand Information and Communication Technology Policy Framework (2011 – 2020) ICT2020"*	Digital policy	2010	National Electronics and Computer Technology Center
5	Thailand	*"The twelfth national economic and social development plan (2017 – 2021)"*	Industrial policy	2016	Office of the National Economic and Social Development Board
6	South Africa	*"Industrial Policy Action Plan 2018/19–2020/21"*	Industrial policy	2018	Department of Trade and Industry
7	South Africa	*"National Integrated ICT Policy White Paper"*	Digital policy	2016	Department of Telecommunications and Postal Services
8	South Africa	*"National e-Strategy. Digital Society South Africa"*	Digital policy	2017	Department of Telecommunications and Postal Services
9	Kenya	*"National ICT Masterplan 2014 – 2017"*	Digital policy	2014	Ministry of Information Communications and Technology
10	Kenya	*"National Information & Communications Technology Policy"*	Digital policy	2016	Ministry of Information Communications and Technology
11	Kenya	*"Industrial Transformation Programme"*	Industrial policy	2015	Ministry of Industrialization and Enterprise Development
12	Nigeria	*"National ICT Policy"*	Digital policy	2012	Ministry of Communication Technology
13	Rwanda	*"Smart Rwanda Masterplan 2015 – 2020"*	Digital policy	2015	Ministry of Youth and ICT

politically address and enforce measures of e-waste management. Even if countries established frameworks for e-waste management, it is crucial to also develop the means to enforce compliance with laws, which are often not in place (Baldé et al., 2017). Thus, having a legal framework in place can only be viewed as a necessary first step, but not as a sufficient condition for the effective public regulation of e-waste.

4.1.2. Example 2: Green ICT

By contrast, the environmental impacts of ICTs which occur during the production and use phases are less frequently considered in the analysed policies. Particularly, the increasing demand for raw materials and electricity that are accompanied by a growing use of ICTs in industry are not mentioned. Moreover, the policies expressed limited awareness of the increases in electricity demand of underlying ICTs infrastructure such as data centres and servers. The content analysis revealed only singular assertions regarding these issues. Hence, we consider this a major blind spot of various policies that we analysed.

The lack of specificity of the analysed policies regarding the direct environmental impacts of ICTs at all stages of their lifecycle is also concerning given that multiple policies mentioned the goal of promoting labels for "Green IT" or "Green ICT" (Table 1). These labels emphasise the need for an environmentally friendly design and use of ICT (Ozturk et al., 2011). Thailand, Philippines, Nigeria and Rwanda propose the promotion of Green ICT labels in their ICTs policies. However, no specific definitions of what Green ICTs are and what conditions they have to fulfil are given. Clear objectives regarding the extent to which industry should foster and use Green ICTs are lacking.

4.2. Expectations about indirect environmental effects of ICTs

Table 5 lists the sum of expectations on indirect environmental effects of ICTs that were expressed in the digital and / or industrial policy of the respective country. We grouped the expectations into the sub-categories of "resource efficiency", "sustainable energy", "transparency" and "systemic effects", indicated by the grey boxes in each row. Policy expectations are abbreviated in the corresponding column in Table 5. A longer version of the paraphrased text passage from the policies is provided in Appendix B.

We find that all policies include expectations regarding indirect environmental effects of ICTs. The degree to which a particular policy addresses one of the identified sub-categories varies greatly between countries. Expectations rarely include more than assumptions about singular (causal) effects and applications of ICTs. Neither do they portray linkages of how different technologies can influence a specific environmental issue in industry, nor do they assess the variety of environmental impacts that a specific ICT may have.

4.2.1. Example 3: 3D print in the aerospace industry in South Africa

Regarding the sub-category of "resource efficiency", the content analysis revealed various goals of using ICTs to increase the overall efficiency of industrial production in order to decrease its environmental footprint. Promoting additive manufacturing for resource efficient production is one case that stands out among the few expectations mentioned within the South African policy for its relatively detailed description of application. Besides specifying the technology, the aerospace industry is also mentioned as a particular field in which environmental benefits may occur. However, as with other statements, the policy lacks quantified goals or estimates of potential savings. Still, it implicitly addresses the twofold advantages of decreased material consumption in manufacturing and lower fuel consumption of airplanes as a direct consequence (Huang et al., 2016) by focusing on the aerospace industry. Also, the negligible size of the aerospace industry in South Africa (0.2 % of manufacturing GDP in 2016, see Industrial Policy in Appendix B), can be linked to the current development state of 3D printing. Given the currently low diffusion of additive manufacturing on a global scale (Gebler et al., 2014), the envisioned

Table 4
Policy expectations regarding direct environmental effects of ICTs.

Country	Policy document	Policy expectation	*Production phase*	*Use phase*	*End-of-life phase*	*Miscellaneous*
China	1	Internet of Things technologies (electronic tags and QR codes) to track the flow of e-waste			■	
	1	Encourage participation in urban waste recycling platforms			■	
Philippines	3	Promote the concept of "Green ICT"				■
	3	Reduce resource consumption of production and minimise waste	■		■	
Thailand	4	Lower resource use of ICT manufacturing	■			
	4	Reduction of energy use within data centres		■		
	4	Raise awareness of ICTs' environmental impacts				■
	4	Establish a "Green ICT" label				■
South Africa	8	Coordinate ICT infrastructure deployment	■			
	8	Minimise harm to human health and the environment at all lifecycle stages	■	■	■	
Kenya	10	Develop e-waste regulations			■	.
	11	Promote the use of environmentally friendly ICT products				■
Nigeria	12	Partner with NGOs to manage e-waste			■	
	12	Minimise impacts of ICT infrastructure construction on the environment	■			
Rwanda	13	Develop e-waste regulations			■	
	13	Waste perceived as a threat to human lives and the environment			■	

Note: Unless otherwise stated, the expectations represent goals that were mentioned in the policies.

application in a smaller domestic sector may present a reachable goal. However, obstacles for the adoption of additive manufacturing in terms of infrastructure, as well as environmental impacts of high customisation of goods, potentially leading to higher resource use, are not elaborated.

4.2.2. Example 4: renewable energy proliferation in Kenya, Rwanda and China

Regarding the sub-category of "sustainable energy", Kenyan and Rwandan policies included general remarks on the role of ICTs for energy production and consumption, but statements are mostly lacking assumptions as to how this is important in the country's context as well as explanations as to how ICTs may contribute to more environmental sustainability in the energy sector. In Rwanda, the Ministry of Infrastructure (MININFRA) recently commissioned large-scale PV solar plants (MININFRA, 2018). Hence, the importance to efficiently use volatile energy sources, aided by ICTs, is likely to increase and crucially hinges on the deployment of adequate infrastructure (Buchana and Ustun, 2015). Thus, it should be considered that ICT-enabled renewable energy integration could pave the way towards improved environmental performance of the sector if policy objectives are specified and implemented.

The Chinese policy, on the other hand, expresses high expectations regarding the role of big data to be a key tool in analysing energy demand and supply and scheduling industrial activity (demand side management, see, for instance, Liu et al. (2015) and Zhou and Yang (2015)). Not only shall private and public sectors cooperate on energy production but it is also expected that consumers will be involved in the decentralised, distributed energy network with a particular focus on renewable energy. The goal of sector coupling between electricity production and the transport sector through electric vehicles and the plan of increased online trading of electricity underline the intention expressed in the Chinese policy to strongly integrate the internet in the energy sector.

With energy in China being largely generated by coal-fired plants (IEA, 2017c) the country has a high level of carbon dioxide output per

Table 5
Policy expectations regarding indirect environmental effects of ICTs.

Country	Policy document	Policy expectation	*Resource efficiency*	*Sustainable energy*	*Transparency*	*Systemic*
China	1	Big data for energy consumption analysis		■		
	1, 2	Steering energy production and consumption		■		
	1	Public-private sharing of environmental data			■	
	1	Electronic tags for recycling and re-use of resources			■	
	1	Online waste trading system			■	
	1	ICTs as a means to foster ecological civilisation				■
Philippines	3	Efficient monitoring of natural resource use			■	
	3	Teleconferences to reduce transportation emissions				■
Thailand	5	Energy-efficient production	■			
	4	Invest in smart grids to optimize consumption of renewables		■		
	4	Awareness of environmentally friendly economic growth				■
	5	Promote knowledge-based economy				■
South Africa	7	Additive manufacturing in aerospace	■			
	9	Resource consumption monitoring			■	
	8	Build a knowledge-based economy				■
Kenya	10, 11	Efficiency of business operations	■			
	10	Efficiently generate and distribute energy		■		
	10	Tracking in the logistics sector			■	
Nigeria	12	Efficiency of energy management		■		
Rwanda	13	Cloud computing and big data for overall production efficiency	■			
	13	Optimise electricity production and consumption		■		

Note: Unless otherwise stated, the expectations represent goals that were mentioned in the policies.

unit of GDP. The Chinese government has pledged to reduce the intensity of carbon dioxide in industrial output with the energy sector being a major leverage to achieve this goal. Benefitting from the integrative function of ICTs at the interface between energy production and consumption, demand side management and sector coupling have the potential to enable better integration of renewable energies in the Chinese energy mix. The policy expectations, however, seem to build on the assumption of quick technological advances (“breakthroughs”) and seamless transition from the current “offline” energy system to an energy system largely incorporating ICTs. Potential structural barriers, such as a lack of investment in the grid to absorb renewable energy installation (Fischer, 2018) are not discussed. Furthermore, no specific renewable energy targets are mentioned and questions about uptake of new technologies in industry and among consumers are not posed.

4.2.3. *Example 5: digital monitoring of resource use in China*

Regarding the sub-category of "transparency", the Chinese policies put emphasis on the use of big data in the monitoring and optimisation of natural resources used in industrial production. To increase transparency, the Chinese government fosters the sharing of data between public and private stakeholders on resources and the environment. For instance, one goal is to collect data through Internet of Things technologies and electronic tags to track waste and set up a trans-sectoral information exchange on resource use.

China has already made several unsuccessful attempts to create an integrated waste recycling system (Xue et al., 2019). The coexistence of formal and informal waste treating, a lack of reliable information about waste content, weak enforceability of legislation and a lack of economic incentives have been hindering progress (Fu et al., 2018; Su et al., 2013). If properly implemented, ICTs could contribute to providing reliable data and thus overcome some of these obstacles. We therefore consider this approach as one of the more promising example of how ICTs are envisioned as a solution for issues of environmental sustainability. However, it remains unclear how positive effects can be achieved on a larger scale beyond trial industrial parks where they are currently implemented. Moreover, technical and economic challenges (such as large-scale, automated data processing and economic profitability) of digital monitoring deployment would need to be addressed.

Regarding the sub-category "systemic effects", there is very little awareness of systemic effects of ICTs in the analysed policies. The Thai and the Chinese policy suggest a transformative potential in ICTs for environmentally-friendly growth. However, there are no direct mentions of rebound effects or other emerging risks in the context of an increased uptake of ICTs in industry. In South Africa and Thailand, digital strategies are centred around the idea of knowledge-based economies and societies, but it is not specified how the concept of a knowledge economy should help reduce resource and energy intensity of industry.

5. Concluding remarks

In this paper, we explored policy makers' expectations in seven African and Asian countries regarding the impacts of the proliferation of ICTs in industry for environmental sustainability. Our analysis showed that policies included some degree of awareness of environmentally detrimental effects related to ICTs particularly focusing on the disposal of ICTs, but in many instances omitted issues related to the production and use of ICTs. Hence, there are several gaps in the recognition of direct environmental effects. Although goals are set out to promote standards for environmentally friendly ICT products, these do not seem to be linked systematically to resource and energy consumption during the production and use of these products. With many LMIC aspiring to grow local ICT manufacturing, we highlight the benefit of integrating these considerations in order to foster more environmentally friendly production of ICTs.

Furthermore, expectations regarding positive indirect effects of ICTs were found in the policies of each country. Similar to direct effects, expectations were rarely specific. We observed mostly one-dimensional expectations and point to the lack of relatedness between direct and indirect effects, for instance when efficiency gains enabled by the use of digital technology were not weighed against resource consumption of the discussed technology. Expectations regarding systemic effects of ICTs were only loosely connected to environmental sustainability in the analysed policies. We suggest that the potential occurrence of rebound effects should be brought into stronger focus of digital and industrial policy making. Efficiency gains from technological progress have failed to decrease the overall environmental burden of industrial production in the past due to rebound effects, e.g. where increases in energy efficiency induced by ICTs were overcompensated and eventually resulted in increased overall energy demand. Currently, systemic feedbacks from ICT-enabled efficiency gains seem to be neglected both in industrial and digital policies. This raises the risk of promoting ICTs as a panacea for environmental issues.

The design of our study comes with some limitations. Expectations from the selected policy documents are not generalisable to other countries in the respective world regions. Having excluded policies that did not express any expectations regarding the impacts of ICTs on environmental sustainability should not deviate attention from the fact that 25 of the 38 screened policies did not, or only barely, cover environmental issues of the digital transformation in industry at all. Even in those countries where explicit mentions have been made, policy expectations are no evidence for subsequent political action and conditions on the ground. Therefore, future research could extend this work by providing context-specific assessments of if, how and by whom ICT-related goals for environmental sustainability in industry are developed, implemented and achieved.

National policies play an important role in shaping industrial development and the digital transformation. In many countries, the digital transformation of industrial production is still in its infancy. Likewise, the industrial sector itself is still being developed in many LMIC. Hence, this may be a crucial point in time to lay the foundation for a digital and industrial transformation that has environmental sustainability at its core. To this end, science and policy makers need to engage into a more active exchange on the certainties and uncertainties related to the impact of the digital transformation on environmental sustainability in industry. While policy makers need to deal with an increasing amount of scientific research, science itself is still very much undecided as to how the digital transformation will impact environmental sustainability of production in a given context. Our study pointed at the specifics of each country's situation – including the stage of industrial development and the degree of digitalisation – that should be investigated further in future case studies.

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Author statement

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Excluded policies due to a lack of thematic fit

	Country	Name of the document	Year of publication	Author
East Asia and Pacific				
	Cambodia	*Cambodia Industrial Development Policy 2015 –2025*	2015	Royal Government of Cambodia
	Cambodia	*Summary on Cambodian ICT Masterplan 2020*	2014	Royal Government of Cambodia
	Malaysia	*Industry4WRD - National policy of Industry 4.0*	2018	Ministry of International Trade and Industry
	Myanmar	*Myanmar Industrial Development 2017*	2016	Ministry of Industry
	Papua Neuguinea	*National Information and Communications Technology (ICT) Policy*	2008	Department of Communication and Information
	Philippines	*DTI Prosperity Plan 2022*	2019	Department of Trade and Industry

	Vietnam	*Viet Nam Industrial Strategy Period 2011 – 2020*	2014	Ministry of Industry and Trade
Sub-Saharan Africa				
	Botswana	*ICT Master Plan*	2012	Botswana Parliament
	Cameroon	*Strategic Plan for a digital Cameroon 2020*	2016	Ministry of Posts and Telecommunications
	Eswatini	*ICT Master Plan*	2010	Parliament of the Kingdom of Swaziland
	Ethiopia	*The National Information and Communication Technology Policy and Strategy*	2009	Federal Democratic Republic of Ethiopia
	Gambia	*The Gambian ICT4D-2021 Plan*	2008	Department of State for Communication, Information and Information Technology
	Liberia	*National Telecommunications & ICT Policy*	2010	Ministry of Posts & Telecommunications
	Malawi	*National ICT Masterplan 2014 – 2031*	2014	Government of Malawi
	Mauritius	*National Information & Communication Technology Strategic Plan*	2011	Ministry of Information and Communication Technology
	Namibia	*Strategic ICT Plan 2017 – 2022*	2017	Ministry of Information and Communication Technology
	Sierra Leone	*National ICT Policy*	2009	Ministry of Information and Communications
	Somalia	*ICT Policy & Strategy*	2019	Ministry of Post, Telecommunications & Technology
	Tanzania	*Integrated Industrial Development Strategy 2025*	2011	Ministry of Industry and Trade
	Tanzania	*National ICT Policy*	2016	Ministry of Works, Transport and Communication
	Uganda	*National Information and Communications Technology Policy*	2014	Ministry of Information and Communications Technology
	Zambia	*National Industrial Policy*	2018	Ministry of Commerce, Trade and Industry
	Zambia	*ICT Masterplan*	2010	National Assembly of Zambia
	Zimbabwe	*Industrial Development Policy 2012 – 2016*	2012	Ministry of Industry and Commerce
	Zimbabwe	*National Policy for ICT 2016 – 2020*	2016	Ministry of ICT, Postal and Courier Services

Appendix B. Extended paraphrased policy expectations

Direct environmental effects

Thailand

- Lower resource use of ICT manufacturing: Lower the natural resource use of ICT manufacturing.
- Reduction of energy use within data centres: Reduce the energy use within data centres.
- Raise awareness of ICTs' environmental impacts: Raise awareness of ICT impacts on the environment.
- Establish a "Green ICT" label: Establish a "Green ICT" label for products manufactured in the country.

Philippines

- Promote the concept of "Green ICT": Promote the concept of "Green ICT".
- Reduce resource consumption of production and minimise waste: Reduce the energy and resource consumption of ICT production and minimise waste production of ICTs.

China

- Internet of Things technologies (electronic tags and QR codes) to track the flow of e-waste: Support the use of Internet of Things technologies such as electronic tags and QR codes to track the flow of e-waste.
- Encourage participation in urban waste recycling platforms: Encourage internet companies to participate in the construction of urban waste recycling platforms, and innovate the recycling model of renewable resources.

South Africa

- Coordinate ICT infrastructure deployment: Coordinate ICT infrastructure deployment in order to minimise negative effects of digging and trenching.
- Minimise harm to human health and the environment at all lifecycle stages: Ensure that the design, use, and disposal of ICTs does not cause harm to human health or the environment.

Kenya

- Develop e-waste regulations: Develop regulations for recycling and disposal of used ICT equipment.
- Promote the use of environmentally friendly ICT products: Promote the use of environmentally friendly ICT products.

Nigeria

- Partner with NGOs to manage e-waste: Partner with NGOs and donor agencies that deal specifically with control, management and disposal of e-waste.
- Minimise impacts of ICT infrastructure construction on the environment: Negative impacts of ICT infrastructure construction on the environment

(CO_2 emissions, radioactivity, e-waste) is perceived as an issue.

Rwanda

- Develop e-waste regulations: Development of legal and regulatory framework to address e-waste.
- Waste perceived as a threat to human lives and the environment: Waste generated by a growing number of devices is perceived as a serious threat to human lives and the environment.

Indirect environmental effects

Thailand

- Energy efficient production: Promote the use of ICTs to increase energy efficiency of production and for environmental protection measures.
- Invest in smart grids to optimize consumption of renewables: Support investment in smart grids to promote renewable energy consumption.
- Awareness of environmentally friendly economic growth: Increase awareness for the role of ICTs in promoting environmentally friendly economic growth.
- Promote knowledge-based economy: Use the proliferation of ICTs to transform the country into a knowledge-based economy and society.

Philippines

- Efficient monitoring of natural resource use: Use ICTs to monitor the environment and natural resources more effectively and efficiently.
- Teleconferences to reduce transportation emissions: Promote internet-enabled teleconferences to decrease the environmental effects of transportation.

China

- Big data for energy consumption analysis: Use big data for energy consumption analysis.
- Steering energy production and consumption: Develop digitally-enabled grid of energy production and consumption among different actors to optimise renewable energy consumption and overall efficiency of energy production and consumption.
- Public-private sharing of environmental data: Share of data between public and private stakeholders on resources and the environment.
- Electronic tags for recycling and re-use of resources: Use the IoT and electronic tags to track e-waste and to improve recycling and re-use of resources.
- Online waste trading system: Establish an online waste trading system.
- ICTs as a means to foster ecological civilisation: Systemically integrate the internet to transform industrial production and facilitate the construction of an ecological civilisation.

South Africa

- Additive manufacturing in aerospace: Use additive manufacturing to increase the efficiency of production in the aerospace industry.
- Resource consumption monitoring: Enable resource consumption monitoring using ICTs.
- Build a knowledge-based economy: Build an inclusive knowledge-based economy against the background of an unsustainably resource intensive economy.

Kenya

- Efficiency of business operations: Use ICTs and mobile communication to increase the overall efficiency of business operations.
- Efficiently generate and distribute energy: Acknowledgement that ICTs are a valuable tool in the efficient generation, distribution and utilisation of energy.
- Tracking in the logistics sector: Use ICTs in the trade, transport and logistics sector for tracking and monitoring purposes.

Nigeria

- Efficiency of energy management: Use the proliferation of ICTs to increase the efficiency of energy management and decrease environmental degradation.

Rwanda

- Cloud computing and big data for overall production efficiency: Use of cloud computing and big data to increase overall resource efficiency of production.
- Optimise electricity production and consumption: Investigate the potential of ICTs to optimise electricity production and consumption.

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