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ABSORBING ADVANCED DIGITAL PRODUCTION TECHNOLOGIES TO FOSTER INDUSTRIALIZATION EVIDENCE FROM CASE STUDIES IN DEVELOPING COUNTRIES

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Absorbing Advanced Digital Production Technologies to Foster Industrialization

Evidence from Case Studies in Developing Countries

Elisa Calza
UNU-MERIT
UNIDO

Smeeta Fokeer
UNIDO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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Abstract

This document has been compiled as guidelines for the realization of case studies to explore the current engagement of developing countries with advanced digital production (ADP) technologies. With the aim of supporting the collection of primary, qualitative evidence on the mechanisms of adoption, use and impact of new technologies among manufacturing firms operating in developing countries, an analytical framework is proposed and discussed. Particular emphasis is placed on the study of the impact of these ADP technologies on various dimensions of firms' performance related to the concept of inclusive and sustainable industrial development (ISID). By identifying three main areas of possible policy action, the document also provides some guidelines to explore policy initiatives that foster the diffusion and application of ADP technologies in developing and emerging countries.

1. Introduction

Several waves of technological advancements have reshaped the manufacturing industry since the First Industrial Revolution (1IR). Today, advanced digital production (ADP) technologies—artificial intelligence, big data analytics, cloud computing, Internet of Things (IoT), advanced robotics and additive manufacturing, among others—represent the latest wave of breakthroughs in production technologies[1]. These technologies have the capacity to profoundly transform production and redefine the future of manufacturing. Yet, the implications of these technological breakthroughs on industrial development are still relatively obscure, in particular for developing and emerging industrial economies.

This document presents some guidelines for the collection of original qualitative evidence on the current engagement of developing countries with ADP technologies, with the aim of providing new insights about how these technologies can contribute to inclusive and sustainable industrial development (ISID) and what conditions need to be in place for firms to be able to exploit their potential. The focus of the case studies collection is twofold: (i) to look at the experiences of some technologically advanced firms in developing countries and to examine the extent to which these actors have adopted ADP technologies in their operations as well as which impact this adoption has on several performance dimensions related to the concept of ISID; ii) considering the main challenges associated with the adoption, absorption and use of ADP technologies to look at some policy initiatives oriented towards supporting this process in developing and emerging countries.

Following this double-level approach, the first part of this document focusses on setting the stage for the collection of case studies on the experience of selected manufacturing firms in developing and emerging countries. It presents an analytical framework that may serve as a roadmap to navigate through concepts and issues related to the adoption, use and impact of new technologies at firm level. Besides investigating general features related to adoption—such as general information about the firm (*WHO*), which specific new technology has been adopted (*WHAT*), which matter does the new technology address (*WHY*), how is the firm using the new technology (*HOW*)—the analytical framework pays particular attention to the impact on firms' activities and performance. The impact of new technologies is analysed on the basis of the three corresponding main dimensions of ISID: *competitiveness, environmental sustainability and social inclusiveness*. The collected firm case studies are clustered around these three impact dimensions according to which dimension is more relevant and informative in the firms' experience.

[1] See OECD (2017) and Mayer (2018).

The second part of this document focusses on case studies involving policy initiatives that foster firms' engagement with ADP technologies in developing and emerging countries. These case studies aim to provide new insights on the role governments and policies play in shaping the diffusion, use and impact of ADP technologies among firms. The considered policy initiatives are analysed along three main policy areas: *setting framework conditions, fostering demand and adoption, and strengthening and building capabilities and skills*. Each of these policy areas entails various issues as well as policy actions that could be undertaken to adapt ADP to ISID. The collected case studies are clustered according to the policy area that corresponds to the main issue addressed by the considered policy initiative.

2. Investigating ADP technologies at firm level

2.1 A roadmap through concepts and dimensions of adoption, use and impact

The aim of the firm case studies is to investigate the extent to which manufacturing firms in developing and emerging countries adopt and use ADP technologies, the main challenges they face, and the impact the adoption of these technologies has on various dimensions of firm performance. For this purpose, a selected number of technologically-advanced firms have been identified in different countries to be included as case studies[2]. Besides providing more insights on the firm-level mechanisms of technological learning and upgrading in a developing and emerging economy, these case studies also represent a set of examples of 'good practices' that could serve as reference points for other actors in similar contexts.

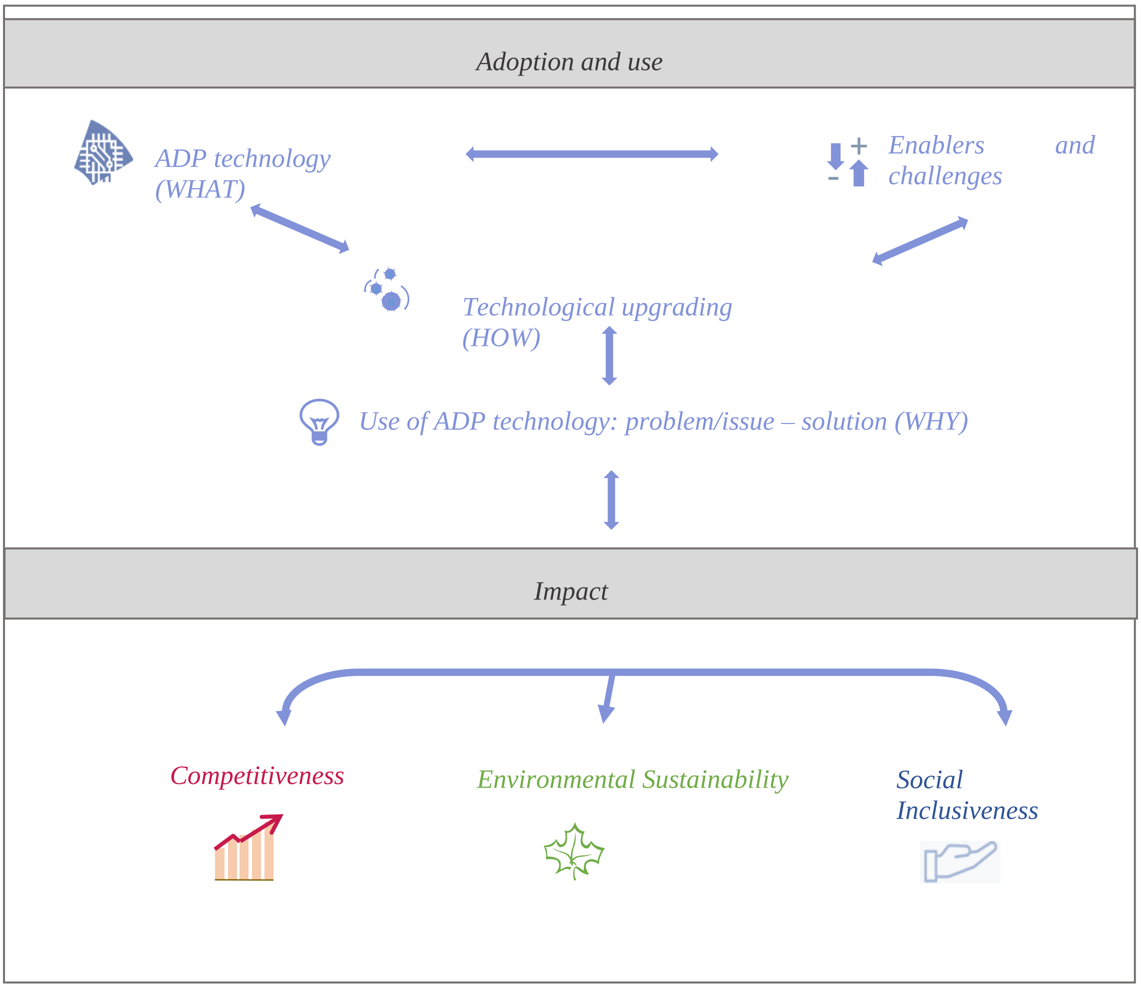
The following sections present and explain the analytical framework that serves as reference for the realization of the firm-level case studies. The analytical framework has the double aim of: (i) providing a roadmap to organize ideas and concepts prior to data collection; (ii) providing guidance for the presentation of the collected material in the form of complete case studies.

Building on the literature on adoption and the impact of technologies and taking a firm-level perspective, the analytical framework develops around the conventional distinction between the *adoption* and *impact* of new technologies. This approach implies two lines of analysis: first, understanding the mechanisms that lead to the adoption of new technologies in manufacturing processes, at the same time considering the social, economic and technological context in which the process of technological upgrading takes place; second, exploring and assessing the impact of these new technologies along multiple dimensions, mostly at firm level, but also keeping an eye on the broader spillover effects in the rest of the economy, society and natural environment.

[2] See the Annex for more information on the methodology followed for the collection of firm case studies.

Figure 1 summarizes the proposed analytical framework, thus serving as a roadmap to navigate through the concepts that make up the backbone of the data collection process and analysis. The upper part of the figure represents the factors related to the mechanism underlying the adoption of new technologies, while the lower part refers to the impact of new technologies along the three main ISID dimensions. The following two subsections describe the two parts of the analytical framework in more detail.

Figure 1 **A roadmap for analysing adoption, use and impact of ADP technologies**



Source: Authors' elaboration.

2.2 The mechanisms of adoption and use of ADP technologies

Understanding technology adoption requires answers to various questions about why and how firms acquire and absorb a new technology, as well as which factors contribute to shaping the adoption decision. To shed some light on the mechanisms of adoption of new ADP technologies, the proposed analytical framework identifies four main factors that are relevant for technology adoption: *ADP technology (technology focus); use of ADP technology; process of technological upgrading; enablers* and *challenges of adoption.* Each one of these four factors can be associated with a specific question, the answer to which represents the starting point for a better understanding of the mechanisms underlying the adoption and absorption of new technologies.

ADP technology *(WHAT)*	*Which new technology has been adopted? What are the features of the newly adopted technologies?*
Use of ADP technology (*WHY*)	*Why has the firm adopted the new ADP technology? How do the new technologies solve the issue?*
Technological upgrading (*HOW*)	*How did the process of technological upgrading proceed? How could the firm embed the new ADP technology in its production systems? How easy/smooth was the process of technological learning?*
Enablers and challenges	*What are the main challenges faced in adopting the new technology? Which factors/actors supported adoption?*

Even if not included in the analytical framework, another important factor that shapes the decision to adopt a new technology is the firm's main characteristics. Thus, an additional, fifth component—and related question—can be included in the analysis:

Firm (*WHO*) *What are the main characteristics of the adopting firm?*

The first part of the data collection focusses on exploring these five questions. However, it is important to keep in mind that the process of adoption, absorption and the use of new technology at firm level is rather complex, as it is the outcome of a simultaneous interweaving of different forces through a non-linear process of learning, which—when successful—leads to the absorption and use of the new technology (notice that the arrows in Figure 1 have a double direction).

WHAT: identifying and describing the ADP technology

Before identifying and describing the main features of the newly adopted technology, it is necessary to define the technological realm of the considered technologies, that is, the technological focus of the analysis. The technological focus corresponds to the latest wave of production technologies applied to manufacturing, namely ADP technologies. These technologies entail the latest development of digital production technologies that belong to one of the technological domains associated with the Fourth Industrial Revolution (4IR), including, for example, various internet-enabled technologies, such as industrial IoT, big data analytics, artificial intelligence and additive manufacturing, among others. Table 1 summarizes the technologies considered, thus defining the broad technological scope adopted for the firm case studies.

These technologies are shaping a new paradigm in manufacturing production and are increasingly blurring the boundaries between physical and digital production systems. The application of ADP technologies in manufacturing and industrial activities gives rise to the concept of smart production and, at plant level, the smart factory. The components of this smart production system interact, communicate and/or control each other's actions, take decisions and implement actions through digital networks of interconnected equipment and sensors, powered by real-time data analytics, machine learning, machine-to-machine communication and other intelligent algorithms[3]. Following this definition of ADP technologies, firms are asked to identify the main ADP technology they have adopted and to present the main features and attributes of the adopted technologies – not from a technological or engineering perspective, but rather highlighting general technological features and related economic aspects of the technology.

[3] See Chukwuekwe, et al. (2016).

Table 1: ADP technologies: definitions and descriptions

Advanced digital production (ADP) technologies	
Industrial Internet of Things (IoT)	IoT represents the next iteration of the internet, where information and data are no longer predominantly generated and processed by humans—which has been the case for most of the data created so far—but by a network of interconnected smart objects, embedded in sensors and miniaturized computers that are able to 'sense' their environment, process data and engage in machine-to-machine communication. The term refers to the interconnection of the internet's network of devices, machinery and objects, uniquely addressable based on standard communication protocols (UNIDO, 2017b).
Machine learning	Machine learning is an application of artificial intelligence. Machine-learning systems use general algorithms to determine how to map inputs to outputs on their own, typically being fed by very large sample datasets (Brynjolfsson et al., 2017). These systems can improve their performance in a given task over time by collecting experience and large volumes of data such as big data.
Big data analytics	Big data are characterized by a higher volume (i.e. a vast amount of data), higher velocity (i.e. frequency or speed by which data is generated becomes available and changes over time), larger variety (i.e. different sources and formats of complex data, either structured or unstructured), and larger granularity than has ever been previously available (OECD, 2017; Eurostat, 2017). The nature of such big data requires new forms of processing to enable their use for enhanced decision-making and process optimization. This is usually defined as BD analytics, which refers to a set of techniques and technologies that allows voluminous amounts of machine-readable data to be generated, stored, accessed, processed and analysed, with the purpose of uncovering valuable information (patterns, correlations, trends and preferences) that can help organizations make informed decisions (Schaeffer, 2017).
Cloud computing	Cloud computing enables ubiquitous, convenient on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. It refers to ICT services that are used over the internet to access software, computing power, storage capacity, etc., where the services have all of the following characteristics: i) are delivered from service providers' servers; ii) can be scaled up or down; iii) can be used on demand; iv) are paid for by the capacity used or are pre-paid (Eurostat, 2017).

Advanced robotics and cobots	Robots are machines that are programmed by computers, and are capable of automatically carrying out a series of more or less complex actions. Robots can be differentiated into industrial robots and service robots. Industrial robots are automatically controlled, reprogrammable, multipurpose manipulators in three or more axes, either fixed or mobile, can be used in industrial automation applications such as manufacturing processes (welding, painting and cutting) or handling processes (depositing, assembling, sorting, packing processes). Service robots are machines that have a degree of autonomy and can operate in complex and dynamic environments that require interaction and coordination with individuals, objects and other devices (for example, when used for transportation, surveillance, cleaning) (Eurostat, 2017). Cobots are robots intended to physically interact with humans. They are designed to learn and adapt to new tasks. They are built with passive compliance features and integrated sensors to adapt to external forces. They tend to be cost-effective, safe, easy-to-use and are suitable for small-scale production and reduced production cycles. They are also portable and easy to configure/reconfigure to perform different tasks.
Artificial intelligence	Artificial intelligence is a branch of computer science that seeks to develop devices that simulate humans' capacity to reason and make decisions. The term usually refers to the employment of AI techniques (such as machine learning, deep learning, computer vision, natural language processing, neural networks, fuzzy logic and self-organizing maps) to provide machines and systems with human-like cognitive capabilities, such as learning, adapting, solving problems as well as in terms of perception. It can be defined as the ability to make computers intelligent and capable of mimicking and predicting human behaviour and solving problems as effectively as humans or even better.
Computer-aided design (CAD) - Computer-aided manufacturing (CAM)	The term CAD-CAM refers to computer systems (hardware and software applications) used to design and draft technical drawings and models, as well as to control and provide instructions to machine tools and equipment to manufacture prototypes, finished products and production runs (Mayer, 2018). CAD systems allow building and viewing a design in a three-dimensional space and facilitate manufacturing processes by conveying information on materials, processes, dimensions, tolerances and dimensions. CAD can be used in isolation or can be integrated with and provide inputs to other computer-aided software such as CAM, which controls the machine tool that creates and/or assembles the physical products.
Additive manufacturing (3D printing)	Additive manufacturing, commonly known as 3D printing, refers to the use of special printers to create three-dimensional physical objects from 3D model data by adding layer-upon-layer through material extrusion, directed energy deposition, material jetting, binder jetting, sheet lamination, vat polymerization and powder bed fusion. AM contrasts subtractive manufacturing methodologies which mould or rotate milling cutters to remove material from a solid block of material (Eurostat, 2017).

Source: UNIDO elaboration.

WHY: understanding the potential of ADP technology

Answering the question why a firm has adopted ADP technology lies at the core of our investigation. It entails understanding the specific potential of new technologies as well as their advantages with respect to traditional production technologies. In this regard, it is important to explore which problem or issue the new ADP technologies address, and why they offer a better solution than more mature and conventional production technologies, that is, in which sense these technology are superior. This aspect provides insights on the expected benefits of these new technologies for firms' activities.

HOW: technological upgrading as a journey

Not much is known about the mechanisms of absorption of ADP technologies; thus, this process of technological upgrading at micro-level is still something of a black box, especially in a developing context. One of the main objectives of the firm case study collection is to shed some light on the features that characterize technological upgrading in manufacturing firms operating in a developing country. In this regard, high importance is placed on understanding how the transition towards the new technology took place, including where the new technology comes from (e.g. from a foreign partner or developed internally), how easily was it absorbed by the firm and whether the process of technological upgrading was successful.

Enablers and challenges: shaping the adoption decision

Many factors may affect the decision to adopt an ADP technology in different directions. These can include internal factors, such as those related to the firm's characteristics, for instance, firm capabilities (e.g. human capital, managerial capabilities, organizational structure, etc.), behavioural features (e.g. leadership, style of management, etc.), structural factors (e.g. firm size, age, sector of activity, etc.). External factors—those related to the context within which the firm operates—can also play a relevant role, for example, the presence of formal institutions and regulations, or the quality of the business environment. Some of these factors represent sector-specific disincentives (e.g. market structure and concentration) and can act as inhibitors and challenge the adoption of advanced digital technologies. At the same time, it is interesting to explore whether external factors such as actors (e.g. foreign companies/partners or domestic actors) can facilitate the absorption of advanced technologies. Besides gaining some insights into what factors are more likely to influence (in both directions) the decision to adopt an advanced digital technology, it is also important to better understand what role firm-level capabilities have played in facilitating such adoption, what (eventual) role the government has had in promoting and supporting the adoption of new technologies (e.g. through information programmes, favouring cooperation, financial support via subsidies/tax credits, etc.), and what the most pressing challenges are that the firm faces.

2.3 ADP technologies and ISID: assessing the multi-dimensional impact

This section presents the part of the analytical framework (Figure 1) dedicated to the analysis of the impact of ADP technologies. In fact, the final objective of the firm case study collection is to shed some light on the following questions: *What is the impact of the ADP technology on the firm? How can these new technologies generate spillovers and what is their impact on the rest of the economy, on society and on the environment?* Although attention is mostly placed on analysing the direct impacts of the adoption and use of ADP technologies on the adopting firm, to better understand the broader implications of new technologies, the potential spillovers to the rest of the economy, society and the environment are considered as well (when possible).

ADP technologies are likely to have a broad impact. This can be represented as a multi-dimensional impact at firm level, which entails different dimensions such as the firm's activity and performance. Thus, arising from the concept of ISID, the proposed analytical framework identifies three main impact dimensions: *competitiveness, environmental sustainability* and *social inclusiveness*. Each one of these impact dimensions is further divided into various sub-dimensions, corresponding to the potential and expected dividends of ADP technologies.

However, it must be kept in mind that the same factors that contribute to shaping the adoption and use of new technologies—such as the features of the technology, the firm's characteristics and the context—may contribute to determining the impact's scope, thus adding further complexity to the process. For example, a firm with a high level of firm capabilities (e.g. better management and more skilled employees) may not only be more likely to adopt new ADP technologies, but its features also make it more capable of better employing the new technologies and reaping larger benefits. The feedback loop is completed as the final impact may, in turn, also shape firms' characteristics as well as their technological domain.

Competitiveness

The first dimension of analysis of the firm-level impact of advanced digital production (ADP) technologies is *competitiveness*. Competitiveness reflects a firm's economic performance, providing the ultimate test of the firm's ability to grow and succeed in its business realm. Competitiveness also shapes the possibilities and scope of a firm's technological trajectory, defining the relative convenience of adopting and using new technologies as well as the speed of technological upgrading. Firms tend to base their decision on whether to adopt new technologies or not precisely on their expectations about the new technologies' effect on their competitiveness. Competitiveness is rooted in different aspects of a firm's activity. To improve the scope of the analysis and to better grasp the scope as well as the quality of the impact of ADP technologies on firms that have adopted such technologies, competitiveness is divided and analysed along five sub-dimensions: *efficiency, product, business model, endogenous innovation* and *linkages*.

Table 2: Competitiveness and its dimensions

Competitiveness		
Efficiency	• Improved capital utilization: productive/automatic maintenance, reduction of idle time, lower inventory rate • Reduced operational costs: flexible, agile and decentralized production, supply chain connectivity, logistics	This sub-dimension considers the impact of new technologies on a firm's efficiency. ADP technologies can optimize operations and increase production efficiency as well as drive the improvement of other indicators of a firm's economic performance, such as returns on investments, profits and revenues. Gains in efficiency are made possible through reductions in operational and production costs and improvements in capital utilization (Andreoni and Anzolin, 2019). ADP technologies enable the integration of production stages and actors into an intelligent smart manufacturing system that—powered by real-time data analytics—is agile, flexible and quick in adjusting to changes in demand and production conditions. ADP technologies can also lead to improvements in the use of fixed assets, reducing idle times and increasing capacity use with automatic and predictive maintenance.
Product	• Quality • Variety • Personalized/smart/ customization	Competitiveness also depends on products' quality and variety: meeting higher quality standards may generate higher value added and access to higher mark-up markets. ADP technologies can significantly increase precision and accuracy along the entire production process, resulting in superior and more cost-effective products. New technologies can also enhance product-service characteristics and functionalities. Smart production systems enable direct involvement of customers in production, facilitating cost-effective customization and the personalization of products.
Business model	• New and data-based services • New pricing models • Customers designing	This sub-dimension examines the impact of new technologies on a firm's business model. New technologies are blurring the boundaries between digital and physical worlds as well as between manufacturing and services. The insights into customer behaviour collected and analysed by smart integrated production systems can allow firms to attach digital services to the final product, offering an integrated product-service package as well as developing new after-sales assistance services. This can lead to a new and more competitive business model, especially in the manufacturing of consumer goods.
Endogenous innovation	• User-led innovation • Patents, copyright • Software/platform development	This sub-dimension considers the impact of ADP technologies on firm-level innovation activities and outcomes. To fully exploit their potential benefits, the integration of new technologies into the firm's production processes may require some adjustments to the firm's conditions, equipment and organization. This can lead to the development of innovations. For example, the

		operationalization of ADP technologies in manufacturing production requires the development of an internal digital infrastructure, such as platforms and integrated software. In addition, the customization possibilities enabled by new technologies allow customers to participate in product design, thereby fostering user-led innovation.
Linkages	• Market actors: suppliers, SMEs, business and industry associations, foreign partners • Non-market actors: universities, research centres	This sub-dimension explores the impact of ADP technologies on firms' linkages and ties with other market and non-market actors. Given their complexity, the adoption of ADP technologies may prompt the firm to seek support from other actors to be able to fully exploit the benefits of these new technologies. In particular, firms may need to develop ties with universities and other education institutions that can provide specific training needed to re-skill the existing labour force or to cooperate in R&D activities. At the same time, new technologies may change and increase the type of market actors the firm interacts with, for example, technologically advanced suppliers or local manufacturing firms. A firm that has adopted ADP technologies can outsource production activities that are still carried out with the use of traditional production technologies to other firms. This can result in the establishment of new industrial linkages.

Source: UNIDO elaboration

Environmental sustainability

The second dimension of analysis of the firm-level impact of ADP technologies is *environmental sustainability*. Environmental concerns associated with the production model based on traditional technologies have turned attention towards alternative modes of industrial development. The environmental sustainability of manufacturing production starts at the firm level, and ADP technologies are opening up opportunities for significant improvements in firms' environmental performance without jeopardizing their efficiency and cost optimization. In fact, the application of these technologies may increase the economic convenience of transitioning towards more sustainable industrial development. New technologies can have a positive impact on environmental sustainability which, in turn, can also generate economic dividends, such as improving capital use. There are two main channels—or sub-dimensions—through which ADP technologies can impact environmental sustainability at firm level: *environmental efficiency* and *environmental goods.*

Table 3: Environmental sustainability and its dimensions

Environmental sustainability		
Environmental efficiency	• Energy efficiency • Input efficiency • Emissions and waste reduction	This sub-dimension explores the impact of ADP technologies on firms' environmental performance, looking in particular at inputs and energy efficiency. By optimizing fixed asset utilization and production parameters, ADP technologies can increase the accuracy and precision of production processes, thereby minimizing redundancies and the waste of inputs. ADP technologies also allow for the replacement of energy-intensive production modes with more energy-efficient ones. For example, the use of software tools that optimize energy consumption may reduce carbon emissions as well as production costs.
Environmental goods	• Eco-friendly materials • Product energy efficiency • Recyclability, circularity	This sub-dimension covers the impact of ADP technologies on the introduction of *green* and environmental manufacturing goods[4]. Embedding new technologies into final products can optimize products' functions and increase their energy efficiency. For example, towing to the transformation of physical products into an integrated product-service package, manufacturers can control and improve a product's overall performance, including its energy consumption. Thus, the digital nature of a physical product can be exploited to enhance its environmental performance.

Source: UNIDO elaboration

Social inclusiveness

The third dimension of analysis of the firm-level impact of ADP technologies is *social inclusiveness*. At firm level, this dimension is often interpreted as the impact on the firm's total number of employees of integrating ADP technologies in manufacturing processes. However, achieving ISID entails more than simply sustaining employment levels, as the path leading from industrial development to shared prosperity also encompasses qualitative aspects of employment and social inclusion. ADP technologies can affect the social dimension of manufacturing production in a broader and more complex way. To improve the scope of the analysis and to better understand the qualitative aspects of the impact of ADP technologies on firms' social inclusiveness, this dimension is divided into three sub-dimensions: *employment conditions, skills and roles and relegated groups*.

[4] Environmental goods can be defined as goods that improve the quality of life while minimizing the use of resources and inputs (including energy) and the emissions of pollutants and waste (including CO_2 emissions and toxic materials) over the product's life cycle (UNIDO, 2017a).

Table 4: Social inclusiveness and its dimensions

Social inclusiveness		
Employment conditions	• Change in labour force (quantity) • Work conditions and safety • Wages and incentives	This sub-dimension investigates the impact of new technologies on the firm's employment level. The net impact of ADP technologies on the size of the manufacturing labour force is still being debated. If ADP technologies, on the one hand, may potentially replace human intervention in an increasingly complex range of tasks, the application of new technologies also increases the quest for specialized staff, on the other, which may imply new employment and career opportunities. In addition to changes to labour force size, new technologies can also impact employment in terms of working conditions and new opportunities. For example, advanced automation solutions and collaborative robots (cobots) in manufacturing plants can improve safety by taking over hazardous and physically arduous tasks.
Skills and roles	• New skills • New roles, task efficiency	This sub-dimension explores the impact of new technologies on employees' skills and role in manufacturing firms. Exploiting the potential of ADP technologies requires new skills and capabilities. Skills that complement new technologies are likely to be favoured, including analytical, technology-related and soft skills (Kupfer et al., 2019). In terms of technology-related abilities, digital skills are playing an increasingly important role, thus fostering demand for specialized training and education programmes. Moreover, the application of ADP technologies in manufacturing can lead to a reorganization of production tasks and a redefinition of workers' roles along the production line.
Relegated groups	• Marginalized customers • Female workers	This sub-dimension focusses on the impact of new technologies on the inclusion of specific groups and individuals, who tend to be marginalized in the industrial model based on traditional production technologies. ADP technologies can promote social inclusion by providing innovative solutions to the needs of vulnerable individuals, whose needs are typically overlooked by manufacturing systems based on mass and lean production technologies characterized by large volumes to lower unit costs. The implications of ADP technologies for female employment also deserve special attention, as it is still unclear whether new technologies would exacerbate or alleviate gender biases in manufacturing. By replacing workers in physically arduous tasks, ADP technologies can open up new employment opportunities for women, thus promoting gender inclusion.

Source: UNIDO elaboration.

The firm case studies provide a comprehensive overview of how technologically advanced firms in developing and emerging industrial economies are adopting and using these new technologies, the impact of the technologies on firms' performance dimensions, and the main challenges firms face during this technological transition period. Section 4.1 presents the complete list of collected firm case studies as well as a summary of the main topic covered in each case (Table 7).

3. Setting the stage for engaging with ADP technologies

3.1 From challenges to policy responses

As already addressed in the discussion of the analytical framework for the firm case studies, governments might play a role in shaping firms' engagement with ADP technologies: they may pose challenges or act as enablers for the adoption of ADP technologies, for instance, by promoting information programmes or financial support. Thus, looking at how some governments in developing and emerging countries are dealing with the surge of new technologies may provide new insights into how to foster firms' engagement with ADP technologies and their effective application.

Building on the components for the design of strategic policies for ADP technologies identified in the joint work of IfM and UNIDO (IfM-UNIDO 2017), our analysis of policy initiatives focusses on three main areas of policy intervention along which policy actions are developed: *developing framework conditions, fostering demand and adoption,* and *building and strengthening skills and capabilities*. These policy areas are relevant for enhancing the readiness to adopt and exploit ADP technologies and represent a response to the challenges firms face in the process of deepening their engagement with ADP technologies, such as lack of adequate regulation, scarce information about the potential of new technologies and lack of qualified staff. Each of these policy areas includes various factors that can be tackled with specific policy actions. The policy initiatives considered in the collected case studies offer examples of how these policy actions can be shaped in practice.

With the aim of fostering a more evidence-based debate to inform the decision-making process of those responsible for designing and implementing national strategies on advanced manufacturing, the collection of case studies on policy initiatives can offer a range of examples of how governments in developing and emerging industrial economies could support firms in successfully integrating ADP technologies in firms' production processes[5]. Without the ambition of providing an exhaustive collection of policy initiatives, these case studies also represent a

[5] The case studies on policy initiatives have been collected through interviews and analysis of material available online (e.g. national strategy documents).

review of possible ‘good practices’ that can serve as references for countries in similar situations. However, caution should be taken when interpreting and drawing general conclusions from the presented policy responses: there are no one-size-fits all solutions (Santiago, 2018) and each policy initiative is highly contextual, having been tailored to address country-specific challenges and to reflect specific conditions (e.g. digital infrastructure, financial system, etc.).

3.1.1 Developing framework conditions

The adoption of ADP technologies requires significant efforts to develop the necessary framework conditions. These framework conditions include, among others, digital infrastructure, regulations and the institutionalization of multi-stakeholder approaches to policy formulation. The importance of digital infrastructure (such as access to fast broadband internet) as a prerequisite for the diffusion of new digital production technologies is broadly accepted (IfM-UNIDO, 2017). In addition, clear emphasis should be placed on the institutional setting for policy, which is particularly important for adapting ADP technologies to ISID, such as the coordination of intra-government bodies and dedicated agencies. A new industrial policy formulation should be based on close collaboration between the private and public sector, fostering a participatory approach as well as the use of consultations. In this respect, policies should promote the establishment of strategic connections with international initiatives and foreign partners – including, for example, MNCs and consulting firms. The opening of channels for international collaboration allows firms in developing and emerging economies to tap into global frontier knowledge and benefit from technology transfers.

3.1.2 Fostering demand and adoption

Policies can help foster the demand and diffusion of new technologies. This requires policy efforts to raise firms’ awareness of the potential use and benefits of such technologies, for example, by introducing dedicated programmes and pilot initiatives on specific technologies, providing incentives to adoption, and stimulating the interest of economic actors. At the same time, instruments and tools to facilitate funding for the adoption of ADP technologies should be introduced, such as novel R&D support schemes and other forms of technology transfers. Moreover, specific policy initiatives should target vulnerable actors, such as small- and medium-sized enterprises (SMEs). These actors represent the large majority of business venues and account for a large share of employment in developing and emerging countries; however, they tend to lag behind from a technological perspective and lack availability and access to financial resources.

3.1.3 Building and strengthening capabilities

Governments can support firms in building and strengthening the necessary capabilities and skills to develop the ability to adopt and effectively use ADP technologies, fully exploiting their potential. Particular attention should be paid to adjusting the labour force's abilities to the changing labour market. This includes promoting new curricula focusing on digital and technological skills as well as on science, technology, engineering and mathematics (STEM) education at various levels. In addition, as this change in required and necessary skills may have adverse consequences for certain workers, it is equally important to support the re-skilling and up-skilling of existing workers to allow them to participate in the ongoing transformation of manufacturing jobs. Policy initiatives could include the development of dedicated learning centres and new approaches to technical and vocational education and training that are aligned with the emerging requirements of firms in terms of skills and abilities.

Table 5: Policy areas, issues and possible actions to engage with ADP technologies

Policy area	Issue tackled	Actions
Developing framework conditions	Regulations and digital infrastructure	• Updating and developing regulatory reforms to facilitate a digital economy • Investment in ICT and broadband infrastructure to foster access to high-speed internet
	Institutional infrastructure and private sector's role	• Institutionalization of multi-stakeholder and participatory approaches (i.e. public-private partnership) • Shared leadership between different ministries (i.e. industry, ICT, innovation, education) with enhanced government coordination
	International collaboration and technology transfer	• Facilitating connections with international initiatives/countries around digitalization and new technologies • Promoting partnerships with foreign organizations and MNCs or consulting firms • Creation of digital parks (i.e. linked to FDI promotion)

Fostering demand and adoption	Access and affordability of ADP technologies	• Develop innovative funding mechanisms and support instruments and/or expanding public funding for ecosystem enablers • Provide targeted support to vulnerable actors (i.e. domestic SMEs) that are technologically lagging behind
	Awareness regarding use and benefits of ADP technologies	• Fostering awareness and interest in new technologies
Building and strengthening capabilities	Development of human resources	• Enhance international collaboration around skill development and employability • Offer/facilitate direct experience, exposure and learning related to new technologies, including new approaches to technical and vocational education and training (TVET)
	Development of research capabilities	• Expanding the scope and number of research institutions

Source: UNIDO elaboration

Section 4.2 presents the complete list of collected case studies on policy initiatives, highlighting the main policy area and actions corresponding to each of the considered policy initiatives (Table 8).

4. List of case studies

All case studies are presented in their full length in the booklet "Absorbing Advanced Digital Production Technologies to Foster Industrialization Evidence from Case Studies in Developing Countries" (UNIDO, 2019). The booklet and the case studies can be accessed here.

4.1 Firm case studies

The firm case studies are clustered by main impact dimension[6]. Table 6 summarizes all impact dimensions and sub-dimensions covered in each firm case study[7].

Competitiveness
AEDesign: Providing innovative services for engaging with ADP technologies in global manufacturing[8]
China Baowu Steel Group Corporation: Introducing smart production into the steel industry[9]
Haier: Reinventing products and business models with the Internet of Things[10]
Thales 3D: Shaping the future of aerospace manufacturing with 3D printing[11]
ZC Rubber: Improving rubber production with cloud computing and big data analytics[12]
Environmental sustainability
AVS Technology AG: Improving the environmental sustainability of water treatment plants with the Internet of Things[13]
New-Tek LLC: Fostering the use of renewable energy with high-tech solar panels[14]
Social inclusiveness
Arçelik: Smart factories and skills for future manufacturing
Genesis Bionics: Using 3D printing to provide innovative solutions for marginalized customers[15]
Mahindra & Mahindra Ltd: Introducing cobots for a blended manufacturing workforce [16]

[6] The decision to cluster the firm case studies by main impact dimension serves the purpose of a clearer presentation of findings and does not intend to limit the depth or the actual scope of each firm case study. As Table 6 shows, information on all impact dimensions can be gleaned from the experience of each considered firm.
[7] Table 6 is a summary and simplification of the wealth of the collected firm case studies in terms of impact. This summary is not exhaustive, and neither is the information on the ADP technologies actually employed by each firm or the impact dimensions highlighted in each case.
[8] This case study has been developed with the assistance of Azhar Zia Ur Rehman.
[9] This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) of China.
[10] This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) of China.
[11] This case study has been conducted with the assistance of Lina Touri from UNIDO Morocco.
[12] This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) from China.
[13] This case study has been conducted with the assistance of Sebastian Perez and Valeria Cantera form the Chamber of Industries of Uruguay (CIU).
[14] This case study has been conducted with the assistance of Nurshat Karabashov.
[15] This case study has been conducted with the assistance of Nurshat Karabashov.
[16] This case study has been collected with the assistance of Rajeev Vijh from UNIDO India.

Table 6: Firm case studies: summary of impact of ADP technology on competitiveness, environmental sustainability and social inclusiveness

	Firm	AEDesign	Arçelik	AVS Technology AG	China Baowu Steel Group	Genesis Bionics	Haier	Mahindra & Mahindra Ltd.	New-Tek LLC	Thales 3D	ZC Rubber
	Main activity/product	Engineering and R&D services	Washing machines	Chlorine plant	Steel	Bionic prostheses	Air conditioning systems	Automotive	Solar panels	Aerospace sector	Rubber and tires
	Country	Pakistan	Turkey	Uruguay	China	Kyrgyzstan	China	India	Kyrgyzstan	Morocco	China
	Main ADP technologies	CAD and computer-aided engineering; industrial sensors; image processing and recognition; machine learning and artificial intelligence; industrial robotics; IoT	IoT; industrial sensors; industrial platform; big data analytics; machine learning and artificial intelligence; augmented and virtual reality	IoT; industrial sensors; big data analytics; machine learning and artificial intelligence	Machine learning and artificial intelligence; edge computing; cloud computing; augmented and virtual reality; industrial sensors; industrial platform	CAD; 3D printing; sensors	IoT; industrial sensors; digital industrial platform; big data analytics	IoT; industrial sensors; industrial platform; cobots	IoT; industrial sensors; industrial platform; big data analytics	CAD; 3D printing	Cloud computing; big data analytics; machine learning and artificial intelligence; industrial platform
Competitiveness	**Efficiency**		Agile, flexible and decentralized production	Remote monitoring, predictive and automated maintenance, down-time reduction	Reducing inventory rate, optimization of operational costs		Agile, flexible and decentralized production	Predictive and automated maintenance, downtime reduction	Remote monitoring, predictive maintenance , downtime reduction		Equipment life time, fault warning, optimization of operational costs
	Products	Higher quality services	Smart, quality, customized		Quality, decreasing non-conformity rate	Quality, customized, specific needs	Smart, quality, customization		Quality	Quality, precision, customized, specific needs	Quality, precision
	Business models		New smart business model, servification	New business model for chemicals			New smart business model, servification				

	Endogenous innovation	Patents, new processes (e.g. in textile)	Industrial platform, user-led innovation	Modular plants	Software/platform, patent (crane)	Software, copyright	Industrial platform, user-led innovation		Patent (film)	Process technology	
	Linkages	Linkages to other sectors/activities/domains	Linkages with suppliers			Linkages with university	Linkage with suppliers, technology providers		Linkages with university	Linkages with local actors (SMEs), university	
Environmental sustainability	**Environmental efficiency**	Green energy (solar), energy and water efficiency	Green energy (solar), efficient system, input optimization	Energy efficiency, optimization of chlorine use, eco-friendly processes	Energy efficiency			Input optimization	Green energy (solar), energy efficiency	Input optimization	Energy efficiency
	Environmental goods					Eco-friendly materials	Smart product energy efficient		Product energy efficiency (higher quality)		
Social inclusiveness	**Employment conditions**	Expanded employment, good working conditions		Expanded employment, good working conditions	Expanded employment, improved safety and less hazardous tasks			Improved safety and less hazardous tasks	Expanded employment, good working conditions		
	Skills and roles	Advanced technical and digital skills required, reskilling (training)	Reorganization, new roles and more autonomy for production workers, new skills required (managerial and soft)				Reorganization, new roles and more autonomy for production workers, new skills required (managerial and soft)		Advanced technological and digital skills required (training)	Advanced technological and digital skills required (training)	Advanced digital skills required
	Relegated groups		Female workers inclusion	Female workers inclusion	Female workers inclusion	Quality products at affordable prices for marginalized customers	Female workers inclusion		Female workers inclusion		

Source: Authors' elaboration.

4.2 Policy initiatives case studies

The case studies on policy initiatives are clustered by main area of policy action. Based on Table 5, Table 7 summarizes the policy initiatives considered for the case study according to the corresponding policy area and possible actions.

Table 7: Policy initiative case studies: summary of policy areas and actions

Developing framework conditions
Implementing the Sino-German Smart Manufacturing Cooperation agreement: Siemens and Baowu[17]
Fostering demand and adoption
Fostering the adoption of cloud computing in Zhejiang Province, China[18]
Facilitating SME participation in smart manufacturing with the C4i4 Lab in Pune, India
Supporting Malaysian manufacturing firms in embracing the Fourth Industrial Revolution[19]
Supporting technological innovation within the realm of the Fourth Industrial Revolution in Pakistan[20]
Building and strengthening capabilities
Facilitating firms in Penang Automation Cluster (Malaysia) in becoming regional and global players[21]

Policy area	Actions	Case study
Developing framework conditions	Facilitating connections with international initiatives and countries around digitalization and new technologies	**China**: Sino-German Smart Manufacturing Cooperation agreement between Baowu and Siemens
Fostering demand and adoption	Develop innovative funding mechanisms and support instrument and/or expanding public funding for ecosystem enablers	**China**: Cloud computing initiative in Zhejiang Province **India**: Centre C4i4 Lab in Pune **Malaysia:** Malaysian 'Industry4WRD: National Policy on Industry 4.0' **Pakistan**: Ignite fund
	Fostering awareness and interest in new technologies	
	Provide targeted support to vulnerable actors (i.e. domestic SMEs) that are technologically lagging behind	
Building and strengthening capabilities	Offer/facilitate direct experience and exposure and learning related to new technologies, including new approaches to technological and vocational education and training (TVET)	**Malaysia**: Penang Automation Cluster and Penang Skill Development Centre (PSDC)

Source: Authors' elaboration.

[17] This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) of China.
[18] This case study has been conducted with the assistance of Hongfei Yue and in collaboration with the Ministry of Industry and Information Technology (MITT) from China.
[19] This case study has been conducted with the assistance of Nidhi Sharma.
[20] This case study has been developed with the assistance of Azhar Zia Ur Rehman.
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Annex

Collecting primary evidence from firms engaging with ADP technologies

The firm case studies provide qualitative evidence on the experience of adoption, use and impact of ADP technologies in ten selected firms in different developing and emerging countries. The information about the firms' experiences in engaging with ADP technologies was collected through semi-structured interviews and field visits, and complemented by available online resources and/or secondary data.

The analytical framework for the firm case studies presented in section 2 of this document served as a guideline for the realization of semi-structured interviews with the selected firm. While a structured interview consists of a rigorous set of questions that do not allow diversions, a semi-structured interview does not require the interviewer to follow a rigid scheme, nor to ask questions in a precise way. A semi-structured interview is open and allows new ideas to evolve during the interview as a result of what the interviewee says. Yet, despite its flexibility, a semi-structured interview must rely on the proposed analytical frameworks to identify the main issues to be addressed during the interview. As already mentioned in section 2, the topics covered during the interview were the following:

- WHAT: type of ADP technology adopted and used by the firm;
- WHY: problem/issue that can be addressed with the application of ADP technologies and opportunities associated with new technologies;
- WHO: description of the firm and its characteristics;
- HOW: firm's process of technological upgrading and absorption of ADP technologies;
- Main IMPACT and implications of ADP technologies along the three impact dimensions of competitiveness, environmental sustainability and social inclusiveness;
- Enablers and challenges: main challenges that constrained and/or factors that facilitated the adoption and effective use of ADP technologies.

Each topic could be addressed by a different set of suggested questions. The final text of the case study reflects these topics and synthetizes the material collected during the interviews, eventually integrated with other reliable sources (e.g. webpage, internal reports, etc.). The proposed analytical framework can also serve as a reference point when compiling the final text of the case studies.

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Vienna International Centre · P.O. Box 300 9 · 1400 Vienna · Austria
Tel.: (+43-1) 26026-0 · E-mail: info@unido.org
www.unido.org