



> Industry 4.0, Urban Development and German International Development Cooperation

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SUMMARY

Industry 4.0 and Advanced Manufacturing are topics of high international relevance. They are currently the subject of intensive debate both in the academic literature and in the practical context of what has become known as the 4th industrial revolution. They are highly dependent on the availability of an adequate digital infrastructure and well-functioning logistics systems and they have a number of repercussions for cities and regions.

Very little work has yet been done regarding the interrelations between Industry 4.0/Advanced Manufacturing and urban development. Consequently, this acatech POSITION PAPER addresses a new field of academic and practical interest, especially as it also adopts an international development cooperation perspective. The study was carried out in close cooperation with the Indian National Academy of Engineering (INAE).

The position paper is based on a number of expert studies on Advanced Manufacturing, logistics and urban development which have recently been published by acatech (Müller, Herzog, 2015), as well as on the project manager's and main authors' own research, e.g. in India. The results of a joint GIZ, acatech and INAE symposium held in India have also been incorporated into the report.

In the report, reference is made to the German Digital Agenda 2014–2017, the GIZ “Quality of Growth” concept, the GIZ/ICLEI discussion paper on the “Green Urban Economy” and the BMZ document “Managing urbanization – towards sustainable cities”. The discussion on the National Platform City of the Future (NPZ: Nationale Plattform Zukunftsstadt) in Germany was also taken into consideration. On the Indian side, the National Manufacturing Plan, the 12th 5 Year Plan 2012–2017 and the 100 Cities Program of the National Government were among the subjects discussed.

The following results can be highlighted:

- Industry 4.0 is a relevant topic for German development cooperation. It has the potential to support all dimensions of qualitative growth as defined by German development cooperation. Furthermore, it can help to promote a green urban economy and has the potential to make an essential contribution to sustainable urban development.
- The potential of Industry 4.0 regarding the implementation of the new post-2015 international development agenda based on the Sustainable Development Goals (SDGs) defined by the United Nations should be carefully explored and included in the international debate. In the context of the topic discussed here, Goals No. 8., 9. and 11.¹ which are related to economic growth, to resilient infrastructure and sustainable industrialization as well as to sustainable urban development, are of special interest here (UN 2014).
- Industry 4.0 has significant potential to positively impact economic development and to contribute to the sustainable development of cities in developing countries and emerging economies. However, the success of its potential benefits is also dependent on the appropriate economic and urban framework conditions being in place. If they are not in place, less positive or even negative impacts of Industry 4.0 on urban development, such as increased noise levels due to 24 hours transportation and commuter movements, changed logistics requirements due to smaller storage units, etc., may prevail. It is especially important for these framework conditions to be addressed by the BMZ and German development cooperation.
- India is a suitable partner for further action, especially in terms of generating Industry 4.0 and urban development good practice examples and working towards improving the framework conditions for successfully preparing the country for further development. The specific

¹ Goal 8.: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
Goal 9.: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
Goal 11.: Make cities and human settlements inclusive, safe, resilient and sustainable.

interest of the Indian industry in Advanced Manufacturing and Industry 4.0 concepts, the extremely difficult, however, improving framework conditions for logistics, as well as severe bottlenecks concerning sustainable and inclusive urban development, and increasingly important demands for a more flexible and locally based urban and regional planning system, play a role here.

Based on these results, the following four recommendations can be made:

- **Carry out an International Industry 4.0 Screening Study:** The study should be global in scope and should identify countries and urban regions relevant to the interface between Industry 4.0 and urban development. The survey should draw on the experience of German industry. Germany's National Academy of Science and Engineering (acatech) could act as a partner and perform a liaison role, owing to its strong links with German industry (through its Senate) and also its strong working relationships with other engineering academies around the world. GIZ, KfW and DEG should also participate and contribute their international experience. The survey could complement an international benchmarking study which is currently under preparation by acatech, although this study focuses on international competitiveness and does not specifically address urban development issues and international development cooperation. Besides analyzing the state of Industry 4.0 as such, its potential positive and negative effects on urban development under different framework conditions should be scrutinized.
- **Develop an Industry 4.0 Readiness Assessment Toolbox:** The toolbox should facilitate informed national and local decision-making. Industry 4.0 will not be a feasible or successful option for development everywhere in the world or even in different parts of the same country. At present, little is known about the supporting framework conditions relating to quality of growth,

economic development, employment and possible integration into international value networks and their impact. It is also not clear which factors are relevant to enabling Industry 4.0 to contribute to a green urban economy and sustainable urban development in each specific case. The toolbox should therefore serve as a guide to national and local administrations for carrying out (rapid) analyses. It should provide elements for an Industry 4.0-related SWOT analysis of the different countries, regions or urban areas. The toolbox should also contain a set of assessment tools regarding e.g. data communication facilities and ICT readiness, cluster analysis, competitiveness and resilience, infrastructure, labor market, general socio-economic characteristics, urban structures and planning instruments, governance and related policies and strategies. The Assessment Toolbox should encompass issues related to quality of growth, the green urban economy and sustainable urban development.

- **Re-examine urban development strategies – Integrate Industry 4.0 Concepts:** Industry 4.0 may facilitate more mixed urban development by bringing the factory back to town, even close to residential areas. This may promote the realization of the "compact city" and the "city of short distances". It is made possible because of two features of Industry 4.0: diminishing lot sizes and the promotion of environmentally-friendly integrated "urban production". However, such positive consequences of Industry 4.0 for urban development will not come about automatically. Numerous bottlenecks and necessary urban and regional framework conditions will need to be addressed, such as negative environmental impact, increase of noise levels due to extended logistics and commuter movement, etc.. Smart, modern planning will also play an important role. Re-examining existing urban development strategies as well as legal frameworks and urban planning systems is therefore indispensable in most countries. Strategically-oriented modern urban

planning practices that directly involve all the relevant stakeholders may help to deliver the potential urban and environmental dividends of Industry 4.0. The BMZ and GIZ should place special emphasis on improving the framework conditions in order to enable the potential benefits of Industry 4.0 to be fully realized. As far as India is concerned, an interesting link could be established with the 100 Smart Cities Program of the Indian Government. In anticipation of the extremely high urbanization rates expected in the coming decades, India is planning to develop 100 smart cities all over the country. Urban retrofits will form part of the program. German development cooperation could contribute its experience in this field and connect the initiative with the results of the NPZ (Nationale Plattform Zukunftsstadt) and the respective Strategic Research and Innovation Agenda of the German government presented in 2015.

- **Create Good Practice Examples – Leading the Way to Industry 4.0:** The good practice examples should facilitate joint learning from practical experience in different sectors and cities. There is a need and opportunity to promote Industry 4.0 in developing and emerging countries in order to keep up with developments in e.g. Germany, Europe, Japan, China and the USA. Joint initiatives could be undertaken in selected manufacturing sectors such as automotive, microelectronics, IT,

pharmaceuticals and food processing in order to explore the opportunities for Industry 4.0 technologies, consult industry with regard to appropriate technologies and their introduction, establish transfer projects and create good practice examples. The creation of international peer-to-peer networks between cities and other institutions could be a first step here to foster international exchange and joint action. As good practice examples cannot be established everywhere at the same time, one approach would be to start with one carefully chosen example agreed upon by all the relevant parties. It should include the most important aspect of Advanced Manufacturing: intelligent production controlling the production processes by Cyber-Physical Systems and incorporating the appropriate Industry 4.0 interfaces/ standards between the business, production, and logistics levels, and it needs to include several tiers of suppliers, among them also MSMEs. India could be a suitable country for establishing a peer-to-peer network and good practice case. The good practice example should be geared towards facilitating Industry 4.0-based production and logistics processes among a small set of MSMEs and exploring and supporting the development of favorable framework conditions in a small or medium-sized Indian city. The good practice example should be accompanied by Industry 4.0 discussion fora and standards activities.

PROJECT

This position paper is based on (Müller, Herzog, 2015) and is the final comprehensive report of the acatech project on "Advanced Manufacturing/Industry 4.0 and Urban Development – Connected, sustainable and urban economic activities in the industrial sector in the context of local, regional and global ICT-based value and logistics chains using the example of selected Indian metropolises". The project was commissioned by GIZ on behalf of the BMZ. It was carried out in cooperation with the Indian National Academy of Engineering (INAE).

The opinions and recommendations expressed here are those of acatech. They do not necessarily reflect the views of the BMZ, GIZ or INAE.

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1 INTRODUCTION – BACKGROUND TO THE PROJECT

Industry 4.0 and Advanced Manufacturing are topics of high international relevance. They are currently the subject of intensive debate both in the academic literature and in the practical context of what has become known as the 4th industrial revolution, a phenomenon based on Cyber-Physical Systems (CPS), the Internet of Things (IOT) and Services and cloud computing. They are highly dependent on the availability of adequate digital infrastructure and well-functioning logistics systems and they have a number of repercussions for cities and regions. Accordingly, it is surprising that little work has been done to date on the interrelations between Industry 4.0/Advanced Manufacturing and urban development.

With its project on “Advanced Manufacturing/Industry 4.0 and Urban Development – Connected, sustainable and urban economic activities in the industrial sector in the context of local, regional and global ICT-based value and logistics chains using the example of selected Indian metropolises”, which was funded by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and commissioned by the Federal Ministry for Economic Cooperation and Development (BMZ), acatech, the National Academy of Science and Engineering, is therefore addressing a new field of academic and practical interest, especially as it also adopts an international development cooperation perspective. The project was carried out in close cooperation with the Indian National Academy of Engineering (INAE).

The six studies commissioned as part of the project focused on Advanced Manufacturing, logistics and urban development. For each of these three themes, one of the studies was written by a German expert team and one by a team of Indian experts. Reference to Industry 4.0 was made wherever possible and necessary. The main authors of the German studies are members of acatech, while the majority of the Indian authors were appointed by the INAE.

The study on “Requirements for and impacts of ICT-based Advanced Manufacturing with special reference to an

international context” focuses on establishing the requirements for international integrated networks to support Advanced Manufacturing based on the current state of Advanced Manufacturing capabilities in terms of Industry 4.0 and the deployment of CPS, as well as identifying the gaps between these requirements and the current state of play. It also identifies potential benefits, especially for MSMEs, from international cooperation in Advanced Manufacturing, using the example of the automotive and electronics industries. Furthermore, it examines the requirements for and impacts of successful international integrated Advanced Manufacturing networks. The report is titled: “Potential of Information and Communication Technology and its Impact on Advanced Manufacturing with Special Reference to the International Context” (Klocke, 2015).

The study on “Requirements for and Impacts of ICT-based Advanced Manufacturing with special reference to the Indian context” (Tiwari, 2015) placed particular emphasis on determining the requirements for international integrated networks to support Advanced Manufacturing based on the current state of Advanced Manufacturing capabilities in terms of Industry 4.0 and the deployment of CPS, with special regard to networks of enterprises involving Indian companies. It also focused on identifying the gaps between these requirements and the current state of play. It deals in particular with country-specific issues relating to the objectives for delivering a complete picture of the requirements with special reference to India.

The study on “Requirements for and Impacts of Logistics for ICT-based Advanced Manufacturing with Special Reference to Urban Development” establishes the main (local, national and international) technical logistics requirements for supporting internationally integrated industrial cooperation and Advanced Manufacturing, as well as identifying the gaps between these requirements and the current state of play. It further identifies industries where logistics plays a key role in enabling Advanced Manufacturing and which

could therefore benefit from international cooperation in Advanced Manufacturing employing integrated logistics ICT systems. It also pays particular attention to the impact on MSMEs. The study is titled: "Logistics integration of suppliers from India in supply chains of German manufacturers – requirements and key action fields under an Industry 4.0 perspective" (Kuhn, Hegmanns, Schmidt, 2015).

The study on "Requirements for and Impacts of Logistics for ICT-based Advanced Manufacturing with Special Reference to Urban Development in India" focuses on the above logistics-related issues with special reference to India. It emphasizes logistics requirements and their impact on local (ICT) innovation, human capital, education, urban infrastructure and development such as resource and energy efficiency, environmental protection, local policy and manufacturing governance. The study is titled: "Path to Growth: Technology Enabled Logistics in India" (Viswanadham, 2015).

The study on "Interrelations between Advanced Manufacturing and Urban Development – the case of metropolitan areas in India" (Sitharam, 2015) highlights current trends in urbanization in India including existing shortcomings and bottlenecks, and it discusses the urban development conditions required for Advanced Manufacturing, as well as possible consequences of Advanced Manufacturing for urban development in the case of metropolitan areas in India.

Finally, the study on "International perspectives of interrelations between Advanced Manufacturing and urban development" has a wider scope. It deals with major trends and urban development preconditions with regard to Advanced Manufacturing, major potential positive and negative effects of Advanced Manufacturing for urban development in an international context and policy recommendations for international development cooperation. The study is titled: "Advanced Manufacturing – Why the City Matters. Perspectives for international development cooperation" (Müller, Schiappacasse, 2015).

A field visit to India was undertaken by the members of the project management and authors of this position paper between May 6 and May 18 2014 in order to discuss project issues with experts in India. A joint GIZ/acatech/INAE symposium was held in early September 2014 in order to discuss the results of the studies and to formulate recommendations for German international development cooperation, with special reference to the German-Indian context. Reference was made to the German Digital Agenda 2014–2017, the GIZ "Quality of Growth" concept, the GIZ/ICLEI discussion paper on the "Green Urban Economy" and the BMZ document on "Managing Urbanization – towards sustainable cities". The discussion on the German National Platform City of the Future (NPZ: Nationale Plattform Zukunftsstadt) was also taken into consideration. On the Indian side, the National Manufacturing Plan, the 12th 5 Year Plan 2012–2017 and the 100 Cities Program of the National Government were among the subjects discussed.

In the remainder of this report, we will begin by providing a brief description of the concept of Industry 4.0 and its relationship with Advanced Manufacturing, logistics and urban development (Chapter 2). Industry 4.0 is then discussed in the contexts of "Quality of Growth", the "Green Urban Economy" and "Sustainable Urban Development", as defined and interpreted by German international development cooperation (Chapter 3). Finally, Chapter 4 presents a number of conclusions and recommendations for international development cooperation.

This position paper is mainly explorative in nature as there is neither sufficient scientific nor practical experience worldwide on the relation between Industry 4.0 and urban development. It attempts to rather develop first hypotheses on the topic than provide data driven or case based analytical evidence. Taking this into consideration, possible future directions of research and practice with special regard to German international development policy are drawn.

The authors would like to thank all the parties who made this project possible. We would especially like to thank the BMZ and GIZ for their financial support, enthusiasm and advice. Special thanks also go to INAE for its generous support with regard to all issues relating to the Indian studies and the organization of the final symposium in New Delhi in September 2014.

The work was conducted in a fruitful and constructive atmosphere and the authors are particularly grateful to the German Embassy in New Delhi, the local GIZ and KfW representatives and the German Consulate General in Bangalore on the German side, as well as INAE on the Indian side, for their help, suggestions and cooperation before and during the field trip to India and throughout the entire duration of the project.

2 THE EVOLUTIONARY PATH TO INDUSTRY 4.0, ITS CHARACTERISTICS AND ROLE AND ITS IMPACT ON URBAN DEVELOPMENT

The term “Industry 4.0” was coined in Germany by the German Federal Ministry of Education and Research (BMBF), the Federal Ministry of Economic Affairs and Energy (BMWi), the Research Union of the German Federal Government, the body in charge of implementing the government’s high-tech strategy and acatech, in order to denote the process of close integration of information and communication technologies (ICT) in manufacturing and logistics through the potential deployment of Cyber-Physical Systems (CPS), leading to a “4th industrial revolution”. CPS enable continuous data collection and analysis across entire value networks through Machine-to-Machine (M2M) communication using the Internet of Things (IOT). There are several research programs funded by the BMBF and the BMWi, while German industry is also very actively involved in these programs. Large industrial and business associations such as the VDMA, ZVEI, and BITKOM have created the “Industrie 4.0” platform in order to coordinate progress in this key field.

There is a tendency to talk about revolutions even when major social and economic changes come about over long periods of time and appear to occur in a more evolutionary than revolutionary manner. This is especially true of the “industrial revolutions”. Previous radical industrial changes in production technology may seem to have taken the shape of revolutions, but a closer look reveals that they were in fact much more evolutionary in nature. The same is true of the impact of the different industrial revolutions on urban development. The path to Industry 4.0 will also be evolutionary (Figure 1).

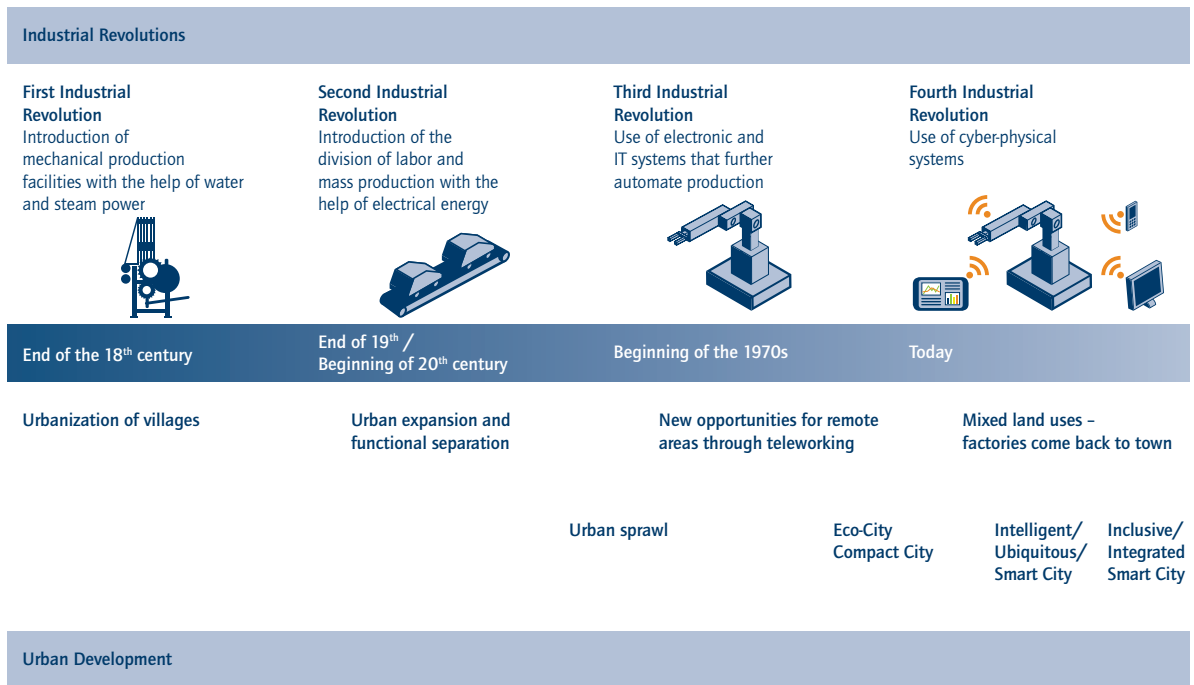
While the first industrial revolution was triggered by large, centralized water- and steam-driven mechanical production equipment that enabled products to be manufactured more quickly and in larger quantities than before, it took almost a century before they came to be ubiquitously employed in production processes at the start of the second industrial revolution. During this period, the new production

technologies led to large-scale urbanization of former rural settlements and contributed to urban growth.

Interestingly, the second industrial revolution was triggered by the opportunity to decentralize the electric power supply, enabling the introduction of relatively inexpensive and much smaller drive units for conveyor belts. The assembly line concept broke down many production steps into individual processes so that employees could become more specialized and production costs could be significantly reduced. This had several consequences for urban development in an increasingly industrialized world. On the one hand, production sites became larger and increasingly disruptive and urban growth was accelerated, often leading to extremely poor living conditions for the working classes. This had an impact on the development of new suburbs with better sanitary and health conditions, as well as improved urban hygiene. On the other hand, mass production made automobiles in particular increasingly affordable for the growing middle classes. This contributed to urban sprawl and the clear separation of land uses in the rapidly growing urban areas, e.g. between industrial and residential areas.

Another century would pass before the start of the third industrial revolution in which the introduction of the first Programmable Logic Controllers (PLCs), electronics and information technologies in the late 1960s would make individual production steps much smarter than in the past. On the urban and regional development front, new hopes were nurtured that ICT could help remote areas to become more competitive and more attractive to businesses and people. It was also hoped that the long commuting distances associated with living in remote locations or in cities on the periphery of metropolitan areas would no longer be a disadvantage thanks to the new opportunities that teleworking provided for working from home, at least on a part-time basis. Nevertheless, there was also a trend towards a return

Figure 1: Industrial revolutions and urban development



Source: Developed by the authors, 2014, based on German Research Center for Artificial Intelligence

to more compact city structures, and the eco-city concept started to become more and more prominent. The concepts of “intelligent cities”, “ubiquitous cities” and “smart cities” would be developed later on, enabling better services and facilitating the use of ICT in everyday life. These concepts continue to characterize the current debate.

It would be another 50 years before further innovations enabled another step improvement in productivity, ushering in the dawn of a fourth industrial revolution based on the development of miniature Cyber-Physical Production Systems (CPPS) and specialized Cyber-Physical Systems. These are tiny data processing units with communication capabilities that use sensors as interfaces to the real world, for example positioning sensors (RFIDs, AGPS, etc.). They are integrated

into electronic and mechanical parts – mechatronics, software technology and networking are the principal basic components of the Internet of Things (IOT) and Services. Fundamentally, it is the ability to assign identities to extremely small batches of products and materials and to locate them precisely that enables the key Industry 4.0 functions of tracking the items involved in production processes at each level of the supply chain, inside and outside of the factory. The IOT is thus a digital representation of real-world production, enabling smart planning, optimization and control of production steps and each section of the supply chain.

However, this automation of complete process networks comes at a price: CPPS systems have an inherent complexity that can no longer be handled by the planning,

optimization and control systems of yesterday – it simply isn't feasible to keep tabs on millions of nodes in a network. This problem can be overcome through a paradigm shift in which computation processes involving the digital representations of production items are decentralized and much more autonomy is assigned to these sub-processes (Klocke, 2015; Kuhn, Hegmanns, Schmidt, 2015).

In order to facilitate the necessary information flow, a comprehensive broadband infrastructure is required for industry, along with new communication standards at the application level so that the subsystems are able to communicate with each other irrespective of their physical location in the real world, thereby implementing the IOT. The industries best suited to the introduction of Industry 4.0 functions are the automotive, mechanical engineering, electrical, chemical, food processing and ICT industries.

Data and information safety and security and their protection against misuse and unauthorized access are critical to the success of Industry 4.0. In Industry 4.0, factories' work organization and the role of employees will change significantly. Participatory work design and lifelong learning will be necessary, as well as training and continuing professional development. Regulatory frameworks will also need to be adapted to Industry 4.0 innovations in terms of legal compliance, protection of corporate data, liability issues, the handling of personal data and trade restrictions.

The expected benefits of Industry 4.0 include increased productivity and efficiency thanks to a reduction in manufacturing uncertainties, as well as resource efficiency thanks to optimization of manufacturing industry's consumption of raw materials and energy. Industry 4.0, together with Logistics 4.0, can thus make a positive contribution to environmentally-friendly industrial production and resource efficiency. Because of its focus on increasing energy efficiency, Industry 4.0 may also have a positive impact on climate change mitigation.

The consequences of Industry 4.0 for urban development are not yet clear. Industry 4.0 can clearly play a role in the continued development of integrated and inclusive smart city concepts and it has the potential to change urban development patterns. It may bring industry back to the city, as cleaner, environmentally-friendly production is much less adverse to other land uses such as housing than previous production technologies. This may have positive consequences for the realization of the "compact city" and the "city of short distances", both of which support more sustainable urban development. However, there is also a number of challenges. For example it is argued that Industry 4.0 may have adverse effects on equity and social inclusion in cities as it may further strengthen the position of better educated and more capable persons while leaving the underprivileged parts of society behind. Moreover, Industry 4.0 makes high demands on favorable urban structures and infrastructure conditions as well as functioning planning mechanisms and good governance. Furthermore, one should also not underestimate disruptions in residential areas, e.g. by commuters and the transport of goods, which may be caused by more flexible Industry 4.0 oriented and 24 hours operating production processes.

The promotion of the Industry 4.0 concept is not confined to Germany. In the international context, the debate is closely linked to the development of Advanced Manufacturing concepts, although this is by no means a new topic. Within academia, for example, "The International Journal of Advanced Manufacturing Technology", one of the major peer-reviewed journals in the field, has been published by Springer since 1985, with 36 issues a year. At a practical level, meanwhile, there are many approaches around the world towards the continuous improvement of industrial production through the use of Advanced Manufacturing technologies (AMT).

Nowadays, this topic ranks high on research agendas and several programs have already been initiated. Companies have established pilot projects in conjunction with

universities and other research institutions. In October 2012, for example, the European Commission issued a Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on "A Stronger European Industry for Growth and Economic Recovery". Markets for AMT geared towards clean production were mentioned as one of six priority areas.

The Communication describes AMT as "a key part of the new industrial revolution. For example, 3-D printing allows production in much smaller quantities than is currently economically feasible, enabling low-cost customised production for new niche products and opening up new market opportunities for innovative MSMEs. Tomorrow's factories will use highly energy- and material-efficient processes, employ renewable and recycled materials, and increasingly adopt sustainable business models such as industrial symbiosis to recover materials and dissipated heat and energy. These technologies represent an important business opportunity, with a global market that is expected to double in size to over € 750 billion by 2020. EU industry is already a world-leader in these technologies, with a world market share of over 35 % and a patent share of over 50 %." (European Commission, 2012, p. 8).

The European Union Task Force on Advanced Manufacturing for Clean Production recommends the integration of Advanced Manufacturing into regional strategies when appropriate and makes reference to the Structural Funds 2014–2020, in particular the European Regional Development Fund (ERDF), as a source of funding for the deployment of Advanced Manufacturing by companies in European regions. "To maximise the ERDF impact towards smart and sustainable growth, under the 2014–2020 programming period, the ERDF rules provide for investments to be concentrated on four key thematic objectives: (1) innovation and research, (2) the digital agenda, (3) support for MSMEs and (4) low-carbon economy. [...] However, as a precondition for the use of the funds the needs for

such investments would have to be included in the smart specialisation strategy." (European Union, 2014, p. 17)

The EU has also set up a program called Manufuture-EU as part of Horizon 2020. Its mission is to "propose, develop and implement a strategy based on Research and Innovation, capable of speeding up the rate of industrial transformation to high-added-value products, processes and services, securing high-skills employment and winning a major share of world manufacturing output in the future knowledge-driven economy." (MANUFUTURE, 2004).

Europe is not alone in its efforts to promote Advanced Manufacturing. For example, the US government published a "National Strategic Plan for Advanced Manufacturing" in February 2012. It states that Advanced Manufacturing "is a matter of fundamental importance to the economic strength ... of the United States" (National Science and Technology Council, 2012, p. vii). In 2012, an initiative called the "Smart Manufacturing Leadership Coalition (SMLC)" was launched in the US. This is a non-profit organization of manufacturing businesses, their suppliers, universities and scientific institutions, government agencies and technology companies. The goal is to develop concepts, standards, platforms and infrastructures in order to facilitate the broad adoption of "intelligent manufacturing" (Smart Manufacturing Leadership Coalition 2014). General Electric (GE) has launched an initiative with similar goals called "Industrial Internet", aimed at bringing together intelligent machines, advanced analytics and people in the workplace. GE is also involved in the SMLC initiative (Evans and Annunziata, 2012).

In Germany, Industry 4.0 is among the top priority themes of the National High-Tech Strategy. It has become an established part of both the policy and research agendas. The German government's recently published Digital Agenda 2014–2017 highlights Industry 4.0 as an important means of safeguarding sustained growth and continuously high

employment rates. It emphasizes the need to get better at tapping into the innovation potential of medium-sized enterprises in particular and underlines the role of start-ups. The Digital Agenda aims to improve the framework conditions for harnessing existing potential.

Nevertheless, the debate about future cities has been slow to incorporate Industry 4.0, even though it is in fact connected with urban development in many ways. One of the initiatives that links Industry 4.0 and Advanced Manufacturing with urban development is the "Morgenstadt" (city of tomorrow) Initiative being carried out by Fraunhofer, Europe's largest application-oriented research organization. This initiative describes the link between the city of the future on the one hand and production and logistics on the other as follows: "In the future, city transportation and handling of goods will happen fluently within intelligent structures of production and distribution - presenting the backbone of sustainable trade, services and urban production. At the same time, essentials have to be provided at any time to all citizens. The city of tomorrow will be involved more deeply in the provision of production and logistic services by providing, planning and monitoring specific urban infrastructure and services for production and logistics. (Morgenstadt)." (Fraunhofer Gesellschaft, n.d.)

Furthermore, "In the city of the future, life and work will be characterized by short distances and by the freedom to realize individual life- and work styles. At the same time, people will have multiple opportunities for participating in decisions on the development of their city. Rigid value chains will be replaced by innovative and flexible value patterns. Regarding consumption and economy, the possession of goods will be less important than the sustainable use of goods and systems. Inhabitants of Morgenstadt won't be exclusively consumers anymore – they become prosumers: producing consumers." (Fraunhofer Gesellschaft, n.d.). Fraunhofer has chosen "Production and Logistics" as one of its 7 research fields in the future city research initiative. The others research

fields are Energy, Buildings, Mobility, Information and Communication, Urban Processes and Organization, and Security.

Finally, Industry 4.0 has also made its way into the German urban research and innovation agenda. The German National Platform City of the Future (NPZ: Nationale Plattform Zukunftsstadt), a major initiative involving four federal ministries under the leadership of the BMBF², has defined major future research topics on urban issues in Germany. The NPZ results published in early 2015, point to the importance of Industry 4.0 and ICT-driven urban development in urban research. In the Strategic Research and Innovation Agenda of the German government, Industry 4.0, logistics as well as their linkages with urban development ("City 4.0") are among the major strategic research themes for the future in Germany. The Strategic Research and Innovation Agenda could act as an important link for activities regarding Industry 4.0, logistics and urban development within the framework of the German international development cooperation on urban issues.

There is also a very interesting link with recent development in India. The Indian government is in the process of implementing a new "100 Cities Program". It wants to create 100 eco- and "smart" urban settlements all over the country as a path towards smart growth and sustainable urban development (India Briefing, 2014). Although the details of the program are not yet clear, re-urbanization schemes and urban retrofits seem to be among the elements included in the program. Conceptually, this strategy is connected with the Indian Corridor Concept which was formulated together with JICA and which aims to improve infrastructure conditions in the country. The Indian-Japanese agreement concluded in August 2014 mentions large-scale Japanese investments spread over five years. Similarly, in September 2014, China pledged to fund two industrial parks and it has also committed to large-scale investments over the next five years. Meanwhile, other countries are in the process of implementing similar activities.

3 INDUSTRY 4.0 AND ITS LINKAGES WITH QUALITY OF GROWTH, THE GREEN URBAN ECONOMY AND SUSTAINABLE DEVELOPMENT OF METROPOLITAN REGIONS

3.1 BACKGROUND

Quality of growth is a guiding mission of German development cooperation as far as sustainable economic development is concerned. High-quality economic growth is seen as a prerequisite for productive and decent employment, which is in turn crucial for poverty eradication and for promoting equitable economic and social development (GIZ, n.d.).

GIZ has defined the following dimensions of high-quality growth:

- Smart growth³, i.e. the promotion of productivity and competitiveness by encouraging the development of a knowledge- and innovation-based economy.
- Sustainable growth, i.e. environmental sustainability where the economic development of one generation does not constitute a burden to future generations, as well as the transition to a green economy.
- Inclusive/shared growth, i.e. the productive participation of all sectors of society in economic processes.
- Resilient growth, i.e. the reduction of economic volatility and mitigation of vulnerability to economic crises and their impacts.
- Integrated growth, i.e. improvement of the framework conditions for the cross-border exchange of goods and services.
- Governance for growth, i.e. the establishment of strong institutions and transparent, participatory decision-making processes.

These dimensions provide a valuable framework for assessing whether and how a new theme might fit into the scope of German development cooperation. They are used here

as a guideline for our analysis. In respect to Smart Growth, Industry 4.0 concepts will clearly contribute to the concept of Smart Manufacturing Ecosystems:

They “must combine four capabilities: human skills, embodied technology in hardware, knowledge (intellectual property) and a large and demanding customer base. All four components grow together to create a productive and competitive industry.” (India Planning Commission, 2013b, p.58).

It is also possible to examine the linkages between Industry 4.0 in an urban context and concepts for the green urban economy and sustainable development of metropolitan regions. While these two concepts are closely linked with the “quality of growth” approach, they have a wider scope and transfer quality of growth to an urban context. The boundaries between the three approaches are soft and there are many overlaps.

The Green Urban Economy is a concept that translates the international and national debates about a green economy to the urban context in order to address urban stakeholders. It is based on the assumption that, in a future where the world is predominantly urban, cities should be pioneers of the transition to a green economy. Key elements of a Green Urban Economy as defined by German development cooperation include the following (BMZ, 2014):

- Inclusive economic growth: “Future growth strategies must no longer focus on quantitative goals alone. Rather, there must be qualitative growth that benefits broad sections of the population. In cities in particular, there is a growing gap between rich and poor, and there are growing groups that do not enjoy adequate social and

² The term “smart growth” as used in this report has to be distinguished from the same term when used in urban planning and development. In the US, for example, “smart growth” is used as a rather widely accepted synonym of “sustainable urban development”. Smart growth concepts in planning try to restrict urban sprawl and to achieve more compact cities.

economic participation." (BMZ, 2014). This is where the linkage with "quality of growth" becomes most evident. Literally, inclusive economic growth refers to the inclusive/shared growth dimension. However, the above description demonstrates that it also encompasses other dimensions of the "quality of growth" approach, such as governance for growth, for example.

- Environmental compatibility: "It is essential that economic growth be decoupled from resource consumption and greenhouse gas emissions. This can be done, for example, by encouraging innovation and environmentally sound technologies. Thanks to their high population density, cities offer opportunities for the establishment of efficient infrastructure networks." (BMZ, 2014). This issue has a particular linkage with the sustainable growth dimension of "quality of growth". Linkages with the smart growth dimension are also apparent.
- Poverty reduction: "Inclusive, ecologically sound growth must be geared toward reducing poverty and giving people opportunities in life. This needs to result in more income opportunities, especially in the low-income sector and in the urban informal sector, and improved access to basic municipal services for the poor and in informal settlements." (BMZ, 2014). This ties in well with the inclusive/shared growth dimension of "quality of growth", with special emphasis on the urban poor.
- The sustainable development of metropolitan regions as defined by German development cooperation is an approach that responds to the needs of urban agglomerations and metropolitan regions and seeks to improve their governance structures. Four priority multi-sectoral areas have been defined as relevant to German development cooperation (BMZ, 2014):
- Metropolitan regions as innovative business regions: "Metropolitan regions provide a venue for the exchange of goods and information between local, national and global businesses. They attract knowledge-based companies and they promote and implement new ideas that facilitate sustainable economic activity. For this to happen,

however, it is essential to create an appropriate framework." (BMZ, 2014). This aspect incorporates most of the features of quality of growth in an urban context.

- Metropolitan regions as inclusive labor markets and residential centers: "By virtue of their economic growth, metropolitan regions provide a wide range of services and jobs from which poor people can also benefit. [...]" (BMZ, 2014). This aspect addresses the inclusive/shared growth dimension of the "quality of growth" approach.
- Metropolitan regions as dense "nexus" networks: "With so many people and so much production and consumption concentrated in one area, metropolitan regions devour tremendous amounts of energy and natural resources. However, given the tightly woven geographical and sectoral links that exist in metropolitan regions, there are good opportunities for improving the efficiency of their material and energy cycles. ..." (BMZ, 2014). This aspect is partly related to the sustainable growth dimension of "quality of growth".
- Metropolitan regions as governance systems: "New governance structures are needed for urban agglomerations in order to organize and control the multi-sectoral challenges they face. ..." (BMZ, 2014). There is a close link between this aspect and the governance for growth dimension referred to above.

All three above described approaches, i. e. Quality of Growth, Green Urban Economy, and Sustainable Urban Development, share a number of overlaps and linkages. Whereas the "quality of growth" approach is focused on economic development in general, the "green urban economy" and "sustainable development of metropolitan regions" concepts translate quality of growth into the urban development context. The next section uses the quality of growth approach as a basis for further analysis. Wherever possible and feasible, references are made to the other concepts. After a number of general observations about Industry 4.0, the Indian situation will be highlighted. Reference will be made to the urban context in general and specifically in India.

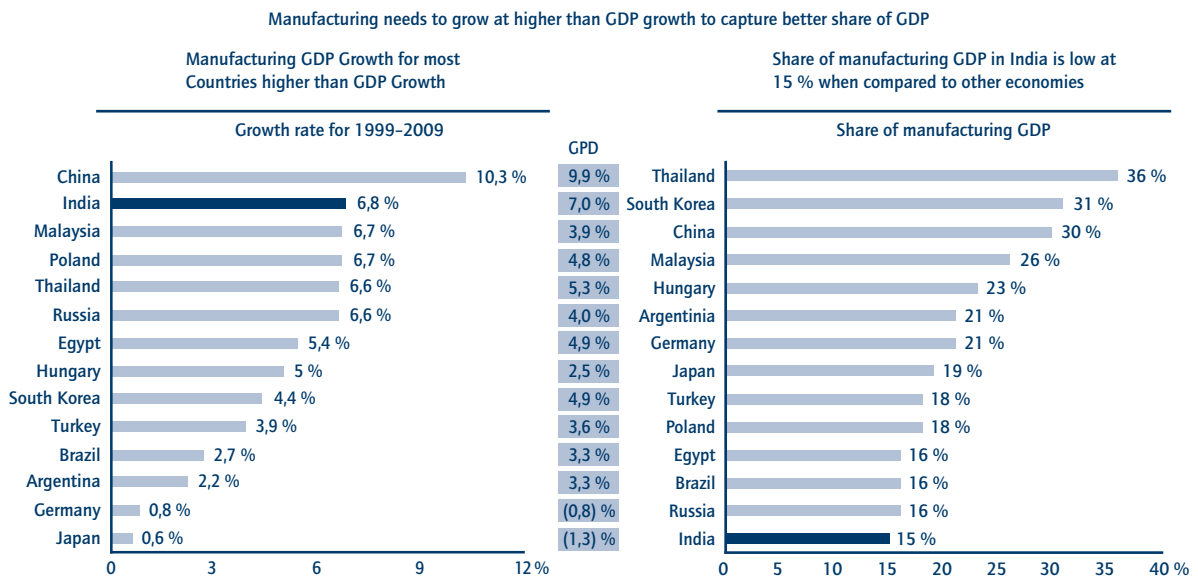
3.2 SMART GROWTH

Industry 4.0 contributes to smart growth and promotes the development of metropolitan regions and cities into innovative business regions. Since manufacturing industry around the world is an important part of the global knowledge society, innovations such as Cyber-Physical Production Systems (CPPS) and the Internet of Things (IOT) and Services drive innovation in Advanced Manufacturing and Advanced Logistics. The requirements for new hardware devices, sensors and software architectures to handle the complexity of the processes in global production and supply networks will lead to completely new solutions, including Internet services through Internet applications for manufacturing and logistics (Tiwari, 2015;

Klocke, 2015). This development will occur mainly in metropolitan regions and larger urban areas (Müller, Schiappacasse, 2015).

In India, the status of Advanced Manufacturing and Logistics is of special importance, since manufacturing has grown more slowly than GDP over the past 15 years and manufacturing's share of GDP has stagnated at about 15 % (see Fig. 2). In recognition of this situation, the National Planning Commission has chosen to prioritize productivity gains over the preservation or creation of jobs: "1.14. The Twelfth Plan's strategy for growth depends crucially on productivity gains as one of the key drivers of growth. Productivity is the additional contribution to growth after taking account of the effect of capital

Figure 2: Manufacturing in India in comparison to other countries



Source: Economic intelligence Unit, Data Monitor, Euro-Monitor, World Bank Work Development Indicators, BCG analysis, quoted in India Planning Commission 2013b, p. 52

accumulation and growth in labour. These traditional sources of growth are not likely to be enough for India in the coming years and we must therefore focus much more on productivity improvements among all constituents: big businesses, MSMEs, farmers and even government. This can be done by improving the business regulatory environment, strengthening the governance capacity of States, investing more in infrastructure rather than subsidies, and by using Science and Technology (S&T) to drive innovation." (India Planning Commission, 2013a, p. 4).

A closer look at manufacturing industry reveals that the Micro, Small and Medium Enterprises (MSME) sector has emerged as the most dynamic sector of the Indian economy in recent decades. This sector contributes about 45 % of the country's manufacturing output and 40 % of total exports, and employs about 69 million people in over 29 million businesses nationwide. Within the MSME sector, there is a significant concentration of micro-enterprises, both in terms of the number of enterprises (94.9 %) and employment (69.2 %), whereas just 4.9 % are small enterprises accounting for 26 % of total employment. MSMEs manufacture over 6,000 products, ranging from traditional to high-tech items (India Planning Commission, 2013b, p. 65). Again, this development has mainly benefited metropolitan regions and urban areas. It is worth noting that many successful and innovative companies do not necessarily reside in the core areas of metropolitan regions but have instead chosen to locate on their periphery, due to a variety of reasons such as land availability, land prices, lot sizes, etc. (Sitharam, 2015).

In this context, it is clear that Industry 4.0 concepts could play an important role in the development of Indian manufacturing, since they support the *smart growth* targeted by the manufacturing plans for both the domestic and export markets.

In view of this strategy, which also includes substantial investments by the National Industrial Corridor authority in

order to upgrade infrastructure facilities and to develop 20 new industrial clusters, as well as the very ambitious plans to develop 100 smart cities, Advanced Manufacturing that implements Industry 4.0 concepts could be a valuable area of cooperation between Germany and India.

Advanced logistics is an integral part of Advanced Manufacturing and an essential precondition for participating in international value networks. Apart from the "hard infrastructure", there is also a need for efficient logistics structures among logistics companies (a very high percentage of Indian trucks are driven by their owners) and a global software infrastructure that enables tracking and tracing at any necessary logistic object level. The highly developed Indian software industry could fulfill a global need in this context.

Additional growth will come about as a result of the growing number of Second-Party Logistics Providers who will take over the logistics functions previously handled by manufacturers, as well as Third-Party Logistics Providers offering manufacturers a one-stop solution for all their logistics services (Viswanadham, 2015).

As logistics also plays a very important role in agriculture and the service industry, there will be an additional benefit to the Indian economy through technology spill-over effects between the different sectors.

As the technologies for Advanced Manufacturing and Logistics are already available in principle, industry and government are called upon to take the necessary steps to facilitate the following (MANUFUTURE 2004, Kuhn, Hegmanns, Schmidt, 2015):

- strong ties between academia and the private sector to foster innovation through research,
- transparency of organizations and information exchange in value networks,
- examples of good industry practices,

- the necessary innovations, such as
 - pertinent use of ICT throughout businesses,
 - the synchronization of materials and information flow within seamlessly integrated transport and logistics systems,
- active participation in international standardization,
- a high standard of education and lifelong learning for human resources,
- updating of the legal framework
 - to reduce the risks for MSMEs,
 - to reform the tax regime in order to reduce the tax burden on firms engaging in R&D,
 - to establish strict protocols for intellectual property rights and
 - to remove trade restrictions.

If India grasps this opportunity, Indian industry will be able to improve its international competitiveness and grow at the intended rate, climbing from the current 16 % of GDP to the required rate of 25 % of GDP in 2017. Indian manufacturing industry will then be in a position to significantly increase its participation in global manufacturing, achieving healthy productivity and creating the 100 million new jobs required by the end of the 12th Five Year Plan in 2017.

All this may result locally in accelerated efforts to promote Advanced Manufacturing. However, until now Indian metropolises are poorly prepared for such developments (Sitharam, 2015): Adverse infrastructure conditions, e.g. poor road networks, unreliable energy and water supply, and ill-functioning sewerage systems, are forcing industries to locate their production sites in the urban periphery or in ex-urban areas, and to establish their own infrastructure systems. Bangalore is a good example for such developments as many industry and high-tech zones have been created at the outer part of the city and metropolitan region respectively (Fig. 3). This underlines how decisive better urban planning and management, appropriate planning instruments as well as transparency and good governance are

so that Industry 4.0 can make a positive contribution to sustainable urban development.

3.3 SUSTAINABLE GROWTH

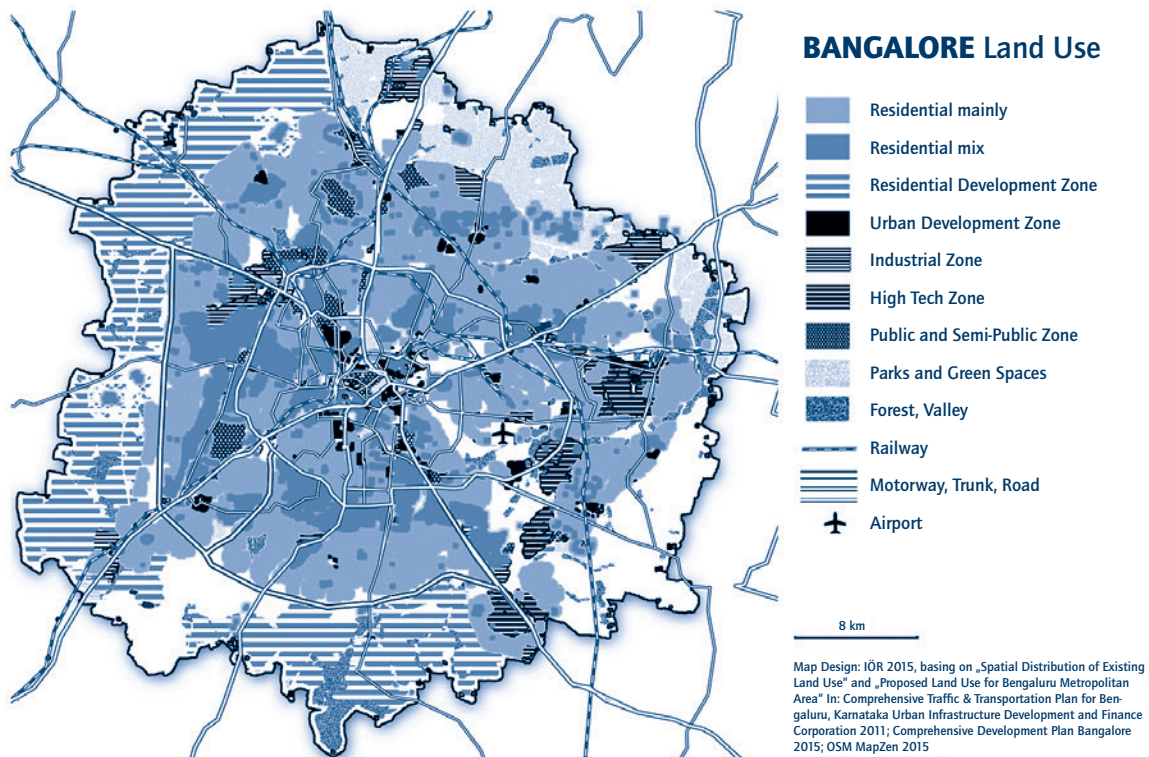
Industry 4.0 makes a contribution to sustainable growth. It contributes to the green urban economy by reducing environmental impacts and fits well with the notion of metropolitan regions as dense “nexus” networks by providing them with the opportunity to improve their materials and energy efficiency.

Sustainability combines environmental, economic and social factors into a single concept. Legal instruments demanding sustainability have been used for a number of years to implement national and European sustainability objectives, e.g. the requirements to incorporate energy management systems and CO₂ emissions certificate trading.

The data basis available for Advanced Manufacturing and Logistics is far superior to anything that existed previously, thanks to the collection of data by sensors throughout the manufacturing and logistics processes. Additional processing of the data on energy and material flows is required in order to generate up-to-date information such as key performance indicators. This is where recent cloud technologies and Big Data analytics come into play. This information can be used to measure and support sustainable growth, since the use of sensor systems and the associated rise in the volume of available information, coupled with flexible and intelligent control concepts, will result in more efficient control and deployment of manufacturing resources in general.

In order to measure industrial sustainability, a Product Environmental Footprint (PEF) conceived as an instrument for the standardization and creation of a shared understanding of products’ environmental impact is under development in

Figure 3: Spatial distribution of existing and proposed land use for the Bengaluru Metropolitan area

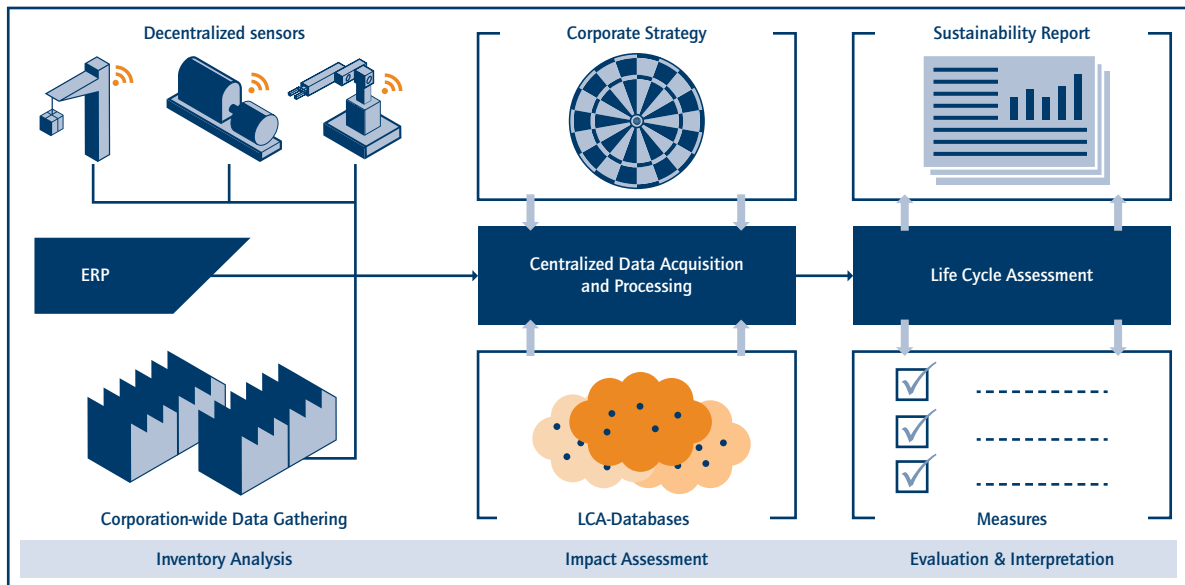


Source: Sitharam 2015

Europe and has already been defined for selected sectors. The PEF specifies and quantifies the environmental impact of a product over its entire life cycle. The equivalent CO₂ emissions during manufacturing, use, recycling or disposal can contribute to the PEF assessment of the product's environmental impact. The PEF for the metal sheets product group will take on an important role in the metalworking industry over the coming years. A total of 38 sustainability indicators in the key areas of Quality of Life, Intergenerational Justice, Social Cohesion and International Responsibility quantify progress in measuring sustainability, including the use of renewable energy (Klocke, 2015).

In an industrial environment, major challenges arise simply from the fact that considerable expertise and willingness to invest are essential if energy and resource efficiency measures are to be implemented. Measures are difficult to evaluate, particularly in terms of their pay-back period and long-term impact, and expertise based on past experience is crucial to doing so successfully. Small and medium-sized organizations in particular can only afford such evaluations in situations where very considerable savings are expected. In view of the requirements for sustainability, it is vital to embed resource efficiency within business processes in order to meet the demands of both energy management

Figure 4: Example of an automatic Life Cycle Assessment in the context of Industry 4.0



Source: Klocke 2015

systems and energy conservation targets. It is important to note that in addition to technological factors, both organizational and social aspects in particular exert considerable influence on any such effort.

In the longer term, it will be essential to conduct life cycle assessments automatically, without the need for large amounts of manual inputting. The conceptual framework is outlined in Figure 4, where the outcome is an environmental audit that is drawn up automatically and parameterized via the central control entities. It can be used to extrapolate cost-saving measures, to review the continuous improvement process or even to initiate public relations activities.

In the Indian context, Cyber-Physical Production Systems provide the option of implementing new forms of energy and resource efficiency in manufacturing. This is of

special significance where the development of new production facilities in an international context permits the introduction of new forms of resource-efficient production. Some Indian companies have already taken steps in this direction, e.g. the MARG group, an infrastructure development company that has entered into a partnership with the US-based Virginia Tech University to promote research into sustainable technologies. They have established a research center near Chennai that will cover broad research areas in sustainable technologies such as water, energy, renewable materials and nano-scale science and engineering.

It will certainly be necessary to develop robust strategies in India to mitigate the risks and challenges associated with manufacturing growth using Industry 4.0 concepts (Tiwari 2015):

- high cost of the necessary technologies,
- energy optimization,
- location and adaptability risk,
- cost-effectiveness of manufacturing products under sustainability constraints in India,
- financial risks of new processes,
- growth in throw-away culture and changing consumer demands,
- resource scarcity,
- climate change,
- waste disposal, waste and pollution control,
- energy security,
- carbon emission crediting and low ceiling of carbon accounts,
- resource depletion, resource conflicts and resource-based political power,
- government regulations to keep up with new business models.

The Government of India has already taken the first steps, establishing compliance assistance centers for MSMEs to raise awareness of better environment management practices and policies for better compliance with environmental regulations (Ministry of Micro, Small and Medium Enterprises, 2012), emphasizing the strict laws aimed at protecting the environment (Ministry of Micro, Small and Medium Enterprises - Development Institute, n.d.a) and pollution control policy (Ministry of Micro, Small and Medium Enterprises - Development Institute, n.d.b). The multiple opportunities for resource optimization will promote manufacturing sustainability, especially in the automobile, pharmaceutical, energy, aerospace and electronics sectors where there is also a strong tradition of German-Indian cooperation:

- strong links between academia, the private sector and government are necessary to follow through on sustainability,
- effective skills training programs pertinent to the different target sectors and customized for all levels of the skill pyramid ranging from technical to business skills,

- design of new collaborative resource consumption models,
- design of business models for managing waste and recycling and adopting cleaner technologies,
- encouragement of new industries based on energy management and renewable energy concepts,
- development of environmentally-friendly materials,
- in contrast to the present dominance of road transport, infrastructure alternatives could take the shape of inter-modal transportation including a high-speed rail freight network with cross-docking and distribution facilities at the stations,
- product and materials distribution centers could be located nearer to the railroad stations and also outside the cities, in accordance with path of goods flow principles (Viswanadham et al., 2008, pp. 34–36).

Sustainability gains may also come from spatial issues (Müller, Schiappacasse, 2015). Industry 4.0 may facilitate mixed urban development and contribute to the realization of the “compact city” and the “city of short distances”. Cleaner production and higher environmental standards lead to better compatibility of industrial sites with other land uses. Thus, industrial production can occur in close proximity to residential areas. Moreover, Industry 4.0-based urban production has the potential to operate with smaller lot sizes due to the modularization of production, meaning that fewer storage facilities will be required. This will allow production facilities to be better integrated into existing urban structures or even located as infill developments in urban regeneration areas.

However, the Indian experience shows that these new urban development opportunities induced by Industry 4.0 will not come about automatically (Sitharam, 2015). Market failures and inadequate governance structures, characterized e.g. by unbalanced and uncontrolled land markets and inadequate and unreliable infrastructure facilities, may force companies to continue to locate on the periphery of

metropolitan regions. This is not only counterproductive in terms of the realization of compact sustainable cities but it also unnecessarily increases environmental impacts, e.g. due to large employee commuting distances, especially in cases where an efficient public transport system is not in place. Like in the case of “smart growth”, this demonstrates the need for good governance, cooperation and modern urban-regional planning.

3.4 INCLUSIVE/SHARED GROWTH

At first glance, the contribution of Industry 4.0 to inclusive or shared growth may be less apparent than in the case of the other dimensions of the “quality of growth” approach. It may also not be immediately obvious how Industry 4.0-based production promotes a green urban economy, e.g. in terms of inclusive economic growth and poverty reduction, or how it can support metropolitan regions as inclusive labor markets, which is one of the characteristics of urban-regional sustainability. Industry 4.0 is often said to be a job killer rather than a job creator, due to its inherent automation of production processes. And it is often seen as exclusive rather than inclusive in terms of socio-economic development. Thus, it may be argued that Industry 4.0 will not be able to substantially contribute to making cities more inclusive.

However, these assumptions are not necessarily true in every case. Industry 4.0 is oriented towards the modularization of industrial production and the facilitation of lot size 1. However, this does not mean that production requires fewer employees and that all production processes along the supply and value chains have to be automated. Nevertheless, job profiles will change in general, with increasing numbers of high-skilled jobs. This will require sound education programs and vocational training activities in respective cities and regions in order to increase regional Industry 4.0 readiness. Moreover, it should be remembered that Industry 4.0-based

production may create new opportunities for small local suppliers and start-ups to become involved in national and/or international value chains thus strengthening the economic development of cities and regions. Furthermore, new job creation opportunities in ancillary industries and in the related service sectors should also be taken into consideration.

Based on the available documents, it can be concluded that the Indian government is aware of the two major aspects of inclusive growth: – it should serve to generate employment and help to provide the means to support people belonging to hitherto excluded groups.

The India Planning Commission (2013a, p. 3) stated: “1.10. There are two reasons why GDP growth is important for the inclusiveness objective. First, rapid growth of GDP produces a larger expansion in total income and production which, if the growth process is sufficiently inclusive, will directly raise living standards of a large section of our people by providing them with employment and other income enhancing activities. Our focus should not be just on GDP growth itself, but on achieving a growth process that is as inclusive as possible. For example, rapid growth which involves faster growth in agriculture, and especially in rain-fed areas where most of the poor live, will be much more inclusive than a GDP growth that is driven entirely by mining or extraction of minerals for exports. Similarly, rapid growth which is based on faster growth for the manufacturing sector as a whole, including MSME, will generate a much broader spread of employment and income earning opportunities and is therefore more inclusive than a growth which is largely driven by extractive industries.

1.11. The second reason why rapid growth is important for inclusiveness is that it generates higher revenues, which help to finance critical programmes of inclusiveness. There are many such programmes which either deliver benefits directly to the poor and the excluded groups, or increase their ability to access employment and income

opportunities generated by the growth process. [...] This is also relevant for the sustainability objective since programmes aimed at making development more sustainable also involve additional costs.”

It is important for the Indian government to strike a prudent balance between these two approaches in order to achieve its inclusion goals. It will certainly help that MSMEs are already the driving force of employment in India today. Industry 4.0 concepts promoted through German-Indian cooperation can thus provide the necessary preconditions for fostering much greater participation of MSMEs in national and/or international value networks, thereby creating or securing more jobs. Moreover, as MSMEs usually lack the necessary R&D capabilities, such cooperation will enable them to keep up with global manufacturing innovations. Accordingly, the Indian government has created the National Innovation Council (India Planning Commission, 2013a, p. 279) in order to

- provide the enabling policy interventions,
- strengthen knowledge infrastructure,
- improve inter-institutional collaboration,
- provide a mechanism for funding business innovations at all levels, especially micro, small and medium-sized enterprises (MSMEs),
- provide a vision through a national-level innovation roadmap.

Another very important aspect of inclusion in India is the government project *Aadhaar* or Unique ID Program, which enables authentication of residents’ identity in real time anywhere in India. This project will create a foundation for more transparent and efficient public service delivery and is regarded internationally as a game-changing approach to inclusion. By providing clear proof of identity, *Aadhaar* will empower India’s poorer citizens to access services such as the formal banking system and give them the opportunity to gain easy access to various other services

provided by the government and the private sector. The program currently covers 600 million people (India Planning Commission 2013a, p. 283).

Regarding urban development is yet very difficult to estimate whether Industry 4.0 will have more positive consequences for achieving more inclusiveness, or whether adverse effects may prevail. Further studies should carefully take into consideration whether and how cities support better education, knowledge creation, and the intergration of small enterprises which hitherto have not had chances to integrate themselves into overarching value chains.

3.5 INTEGRATED GROWTH

There can be no doubt that Industry 4.0 contributes to integrated growth. As the global manufacturing industry relies on international value chains, integrated growth is a direct consequence of Advanced Manufacturing and Advanced Logistics at the international level. An important prerequisite is the international transport of materials and goods (Tiwari, 2015; Klocke, 2015; Viswanadham, 2015; Kuhn, Hegmanns, Schmidt, 2015).

In India, the National Planning Commission clearly recognizes this fact as being valid with regard to both the national transport network and international value networks (India Planning Commission 2013b, p. 197): “First, a more integrated approach is required to be taken of transport as a whole. Our vision for transport should be guided by a modal mix that will lead to an efficient, sustainable, economical, safe, reliable, environmentally friendly and regionally balanced transportation system. Choices will need to be made on the priorities to be placed on different investments. Decisions on road expressways, dedicated rail freight corridors, high-speed trains and movement through inland waterways or coastal shipping must be taken holistically so that the objective of speed and efficient energy

usage is achieved. Policy decisions should be based on life cycle energy costs of different transport modes."

In order to enable smooth international logistics, it will also be important to foster the transition from Second-Party Logistics Providers to Third-Party Logistics Providers offering a one-stop solution for all manufacturers' logistics services (Viswanadham, 2015).

Given that the technologies for Advanced Manufacturing and Logistics are already available, industry and government are called upon to take the necessary steps to resolve the legal, economic and infrastructure constraints, e.g.

- clear and simple import and export regulations,
- removal of regulations stipulating minimum Indian ownership of 51 % in joint ventures,
- the logistics system should consider import and export regulations for delivery management,
- the necessary innovations on the basis of industry 4.0 concepts, such as
 - pertinent use of ICT throughout businesses,
 - the synchronization of materials and information flow within seamlessly integrated transport and logistics systems,
- updating of the legal framework to
 - reform the tax regime in order to reduce the tax burden on firms engaging in R&D,
 - establish strict protocols for intellectual property rights,
 - remove customs restrictions and prevent goods from experiencing long delays at customs.

A well-functioning logistics and transport infrastructure is of the utmost importance for urban development and the location of production facilities (Sitharam, 2015; Müller, Schiappacasse, 2015). If these are not in place, and if reliable transportation of materials and goods cannot be guaranteed, it will not be possible to convince enterprises to locate their

facilities in the urban core areas. In fact, transportation problems are among the reasons why enterprises are currently still "moving out" to the periphery of urban areas. In such a situation, the potential benefits of Industry 4.0 such as the generation of mixed urban land uses and the location of production sites in inner-city regeneration areas are lost. Moreover, commuting distances grow instead of becoming smaller.

3.6 RESILIENT GROWTH

Resilient growth does not imply the avoidance of all risks at all costs – it is strongly connected to risk management. In the past, resilience in businesses was mostly driven by experience. However, with data- and process-driven Advanced Manufacturing based on Industry 4.0 concepts it is now possible to model the processes involved to a much greater extent.

Accordingly, risks can be mitigated by deploying joint risk management procedures designed by cooperating enterprises and backed up by government policies to integrate resilience into international Advanced Manufacturing networks. MSMEs can plausibly tackle the inherent risks by adopting new Advanced Manufacturing protocols (Tiwari, 2015; Klocke, 2015):

- MSMEs' business models should provide robust protection against multiple external factors, such as changes in technology trends, frequent variations in customer demands and global recessions resulting in low demand.
- Involvement of multiple stakeholders from government, academia, Foreign Direct Investment and the general public could mitigate the risk of insolvency due to highly investment-intensive activities, such as innovations, disruptive technologies and high-end technology acquisitions.
- Government must update the legal framework to create easy business exit policies for MSMEs in the event of business problems.

- Regulatory bodies must work towards reforming the tax regime in order to reduce the tax burden on firms engaging in R&D activities and innovation.
- Strict protocols for intellectual property rights (IPR) must be adhered to at the international level.
- Firms must form international and national industrial networks to facilitate the adoption of innovative mechanisms to cope with uncertainty through participation in the provision of systemic solutions.
- The treaties and policies regarding promotion of sustainability and environmental obligations, such as ceilings for carbon trading, formulation of global renewable energy policies, etc., must be optimized to provide equal industrial development opportunities to all countries.
- Large companies and global conglomerates that have already established their risk management policies for cyber risks and knowledge management could mentor MSMEs or work with their suppliers in order to improve their structures and mitigate their vulnerabilities, in the interests of promoting growth.
- The major risk of delays to business operations could be minimized by optimizing the variables such as the choice of manufacturing location, decisions on customer interactions, total business cost and target market segment.
- Process fluctuations can result in uncontrolled instabilities in the process chain ("bull-whip effect"). Broad recording of process fluctuations and real-time control will return processes to a stable state even before risky events can pile up.
- Suppliers of industrial information technologies must resolve the challenges associated with classical data recording, cloud technology and data analysis concepts.
- Risk management and resilience management should be promoted at both the corporate level and the level of the authorities responsible for infrastructure management in order to reduce the frequency and impact of disruptions to industrial processes in production and logistics

In globally distributed supply networks, disruptions occur rather regularly. Robust supply chains that are able to cope with unforeseen events are a vital business capability in rapidly changing value networks. In addition to a resilient and flexible supply network infrastructure, businesses need highly accurate risk detection capabilities that employ Big Data tools and techniques. Moreover, logistics providers can secure customer operations by performing predictive analytics on a global scale.

Specific Industry 4.0 concepts can contribute to risk mitigation as follows:

- The implementation of new sensor concepts to record field data enables resilient production processes to be developed and operated.
- Reservations relating to opening up interfaces and large-scale data analysis must be overcome jointly by the participants in international value networks.
- Test procedures to check manufacturing and logistics resilience at all tier levels must be jointly designed and agreed upon among cooperating value networks.
- Resilient process chain design can be achieved by the order-dependent combination of manufacturing steps.

Risk mitigation must therefore be a part of regular logistics operations rather than an intervention carried out after the event as is usually the case today. The operations manager is familiar with normal conditions and also how anomalies arise and should be tasked with handling abnormal situations. With regard to stable Advanced Logistics for Advanced Manufacturing in international value networks, there is also a set of strategies for helping government, corporations and individuals to manage the risks so that they can either be avoided or so that process resilience can be achieved if avoidance is too expensive (Viswanadham, 2015; Kuhn et al., 2015):

- Avoid the risk whenever possible: It is risky to source from countries where there is a possibility of war or weather problems, or from companies with troubled finances.

- Mitigate the risk directly by improving flexibility in order to reduce the impact or likelihood of the risk at its source. Dual sourcing is one simple solution.
- Adapt to the risk by preparing for it, e.g. earthquake-resistant building construction, rapid evacuation in the event of floods and securing access to buildings.
- Transfer the risk to a third party such as an insurer or through more sophisticated hedging strategies.
- Mitigate the risk using order-based governance involving partner selection, coordination, monitoring and execution. For each order, a 4PL can select the logistics partners in order to minimize the risks associated with the logistics processes.

As regards the relation with urban development, resilience and risk reduction is very closely related to the capacities of the urban and regional planning system, the available planning tools, and the existing governance regime. Sound planning and implementation can contribute to minimizing risks by promoting better organized and reliable city patterns and infrastructure systems. The availability of appropriate and effective urban planning tools is decisive for the implementation of planning concepts oriented towards risk reduction. And the governance regime may help to provide for transparency and participation.

3.7 GOVERNANCE FOR GROWTH

Industry 4.0 is closely related to governance for growth. Especially for Advanced Manufacturing and Advanced Logistics in international value networks, it forms part of all the growth drivers for businesses and governments (Tiwari, 2015; Klocke, 2015; Viswanadham, 2015; Kuhn, Hegmanns, Schmidt, 2015).

In addition to the necessary efforts of businesses to integrate ICT and CPPS functions for Advanced Manufacturing, there must be committed efforts on behalf of governments

to determine current deficits and implement timely remedial policies. The most important measures in India are:

- National Manufacturing Competitive Programme (NMCP), 2010 (Ministry of Commerce & Industry),
- National Manufacturing Policy, 2011 (General Knowledge Today, 2013),
- Working Group on Micro, Small & Medium Enterprises (MSMEs) Growth for 12th Five Year Plan (2012–2017) (India Planning Commission 2013b, p. 61),
- National Innovation Council (www.innovationcouncil.gov.in),
- Institutes of national importance for skills training and consultancy, e.g. the Federation of Indian Chambers of Commerce & Industry (FICCI) (Federation of Indian Chambers of Commerce and Industry, n.d.),
- The Confederation of Indian industry (CII) (CII, 2014).

The NMCP is aimed at strengthening and assisting with the realization of lean manufacturing, including ICT and the establishment of demo rooms by the Ministry of Small Scale Industries. The current Five Year Plan emphasizes the importance of SMSEs and requires the government to establish the following governance measures and policies to “improve their technological capabilities by focusing on

- Providing access to risk capital
- Establishment of standards for industry
- Improving industry/research institute/academia interaction, mostly in clusters
- Stimulating demand/providing scale through preferential treatment in government purchases.” (India Planning Commission 2013b, p. 61).

Technology and quality improvements are also identified as a top priority, along with supporting entrepreneurial and management development. Emphasis is placed on raising awareness for investment in intellectual property; this has

been a concern with the advent of global multinational companies in India, as most MSMEs are not concerned about getting their innovations patented, which prevents India from claiming its innovation potential. A holistic framework of IPRs in collaboration with international authorities is therefore indispensable in today's competitive manufacturing environment in order to empower the Indian technology base.

Governance also plays an important role in creating the right urban framework conditions for Industry 4.0, e.g., regarding urban planning, development strategies, infrastructure, logistics, etc. In this context, metropolitan regions and urban areas should be seen as governance systems. They need to be reformed so that they are able to organize and control the multi-sectoral challenges facing them, especially those linked to Industry 4.0.

4 RECOMMENDATIONS: INDUSTRY 4.0 IN INTERNATIONAL DEVELOPMENT COOPERATION

Industry 4.0 is a topic that is relevant to German international development cooperation. It has the potential to support all the dimensions of qualitative growth as defined by German development cooperation. Furthermore, it can help to promote a green urban economy and can make an essential contribution to sustainable urban development.

The potential of Industry 4.0 regarding the implementation of the new post-2015 international development agenda based on the Sustainable Development Goals (SDGs) defined by the United Nations should be carefully explored and included in the international debate.

Industry 4.0 has high potential to positively impact economic development and to contribute to the sustainable development of cities in developing countries and emerging economies. However, the success of its potential benefits is also dependent on the appropriate economic and urban framework conditions being in place. These framework conditions should be addressed by the BMZ and German development cooperation.

Based on these considerations and on specific studies on Advanced Manufacturing, logistics and urban development by German and Indian experts, the following recommendations have been formulated.

4.1 CARRY OUT AN INTERNATIONAL INDUSTRY 4.0 SCREENING STUDY

Industry 4.0 will result in significant changes to industrial production and international value chains around the world. However, not all developing countries and emerging economies will be affected in the same way and at the same time. Some countries may be among the pioneers, while for others Industry 4.0 will only become relevant at a later point in time. It is not yet clear in which countries and in which regions Industry 4.0 will play a major role in the near future

and it is also not yet clear which specific role it may play. These factors may be determined by the capacities and roles of the manufacturing sectors and respective framework conditions relevant to Industry 4.0 in the individual countries.

German development cooperation, i.e. the BMZ and GIZ, should therefore commission a screening study on the current relevance and future potential of Industry 4.0 in developing and emerging countries. The study should be fundamentally global in scope and should clearly identify countries and suitable regions and urban areas within these countries that could be candidates for future German development cooperation in the field of Industry 4.0. Besides the identification of potential partner countries and regions, relevant linkages between Advanced Manufacturing, logistics and urban development should be studied and specified. Their potential contribution to the major objectives and guidelines of German development cooperation should be highlighted.

As a starting point or one element of the screening study, a survey could be conducted among the relevant German companies involved in global Advanced Manufacturing activities. The survey should draw on the experience of such companies in order to identify

- relevant countries and regions,
- relevant economic/manufacturing sectors,
- major bottlenecks and
- potential solutions to existing problems

regarding the introduction of Industry 4.0 in order to contribute to quality of growth, the urban green economy and sustainable urban development. The results of the study could be used as a basis for further country-specific strategies and projects.

acatech, Germany's National Academy of Science and Engineering, could act as a partner and perform a liaison role here, since it is able to draw on all the necessary interdisciplinary

expertise through its members and its close links with German industry (through its Senate), as well as its strong working relationships with other engineering academies around the world. GIZ, KfW and DEG should also be involved and contribute their international experience, together with industry associations such as the VDA, VDMA and ZVEI and the international chambers of commerce.

The survey could complement an international benchmarking study which is currently under preparation by acatech⁴, although this study focuses on international competitiveness and does not specifically address urban development issues and international development cooperation. Besides analyzing the state of Industry 4.0 as such, its potential positive and negative effects on urban development under different framework conditions should be scrutinized.

4.2 DEVELOP AN INDUSTRY 4.0 READINESS ASSESSMENT TOOLBOX

Industry 4.0 has the potential to become a popular catchword at the policy making level, as it stands for forward-thinking and innovative development strategies. National and local decision-makers may be tempted to use Industry 4.0 prematurely and to embark on their respective strategies without scrutinizing the specific current potential of Industry 4.0 for local, regional and national development.

However, Industry 4.0 will not be a feasible or successful option for development everywhere. At present, little is known regarding the supporting framework conditions related to quality of growth, economic development, employment, and possible integration into international value networks and their impact. It is also not clear which factors are relevant to enabling Industry 4.0 to contribute to a green urban economy and sustainable urban development work in each specific instance.

It is therefore proposed that an Industry 4.0 Readiness Assessment Toolbox should be developed. The toolbox should facilitate a sound and realistic analysis of the current potential and expected benefits of Industry 4.0 in each specific case, in order to avoid haphazard and hasty decision-making and promote well-informed decisions on future strategies.

The Industry 4.0 Readiness Assessment Toolbox should serve as a guide to national and local administrations for carrying out (rapid) analyses. It should provide elements for an Industry 4.0-related SWOT analysis of the different countries, regions or urban areas. The toolbox should also contain a set of assessment tools regarding e.g. data communication facilities and ICT readiness, cluster analysis, competitiveness and resilience, infrastructure and labor market, general socio-economic characteristics, urban structures and planning instruments, governance and related policies and strategies. The Assessment Toolbox should encompass issues related to quality of growth, the green urban economy and sustainable urban development. It should help to carefully weigh up the potential economic and image gains of a country, region or urban area that could result from an Industry 4.0-based strategy, as well as realistically assessing its chances of being successful.

4.3 RE-EXAMINE URBAN DEVELOPMENT STRATEGIES – INTEGRATING INDUSTRY 4.0 CONCEPTS

In principle, Industry 4.0 facilitates more mixed urban development by bringing the factory back to town, even close to residential areas. This promotes the realization of the "compact city" and the "city of short distances". It is made possible because of two features of Industry 4.0: diminishing lot sizes and the promotion of environmentally-friendly integrated "urban production":

³ Industrie 4.0 – Internationaler Benchmark, Zukunftsoptionen und Handlungsempfehlungen. The number of countries included in this project, especially developing and emerging ones, is very limited (e.g. India, Saudi Arabia, Nigeria, Indonesia, Brazil, China, Malaysia, Singapore, South Korea).

- Industry 4.0 facilitates the modularization of industrial production, possibly leading to smaller and more specialized production facilities. The smart factory will also require less storage capacity due to real-time information processing, advanced logistics and just-in-sequence supply. This may result in less overall land “consumption” for industrial purposes. Smaller industrial production facilities are more easily and successfully integrated into the existing urban pattern and located in existing neighborhoods, e.g., as part of urban renewal or urban retrofit projects.
- Industry 4.0 will lead to cleaner production and enhanced energy efficiency through the use of sensor technology, high-precision control and real-time information enabling, e.g., the control of many more electrical motors in production facilities than today (only about ~20 %). Material consumption and waste will also be reduced and smart products can be recycled more easily. All in all, this will make a contribution to improving the environment and mitigating climate change. Given appropriate solutions to possible disruption caused by logistics activities, it will be easier to locate environmentally-friendly production facilities within or in close proximity to residential areas.
- If public infrastructure services are inadequate and unreliable, companies may design their production sites so that they are capable of dealing with potential difficulties, making them self-sufficient in terms of water, energy and sewerage. This may lead to environmental threats, for example to the groundwater table as a result of uncoordinated and increased water consumption, as well as the inefficient use of natural resources. It may also increase actual land “consumption” even by those companies that follow the Industry 4.0 approach. The situation may be exacerbated if the speed of urban growth outstrips the local capability to establish the necessary infrastructure, thus widening the gap between serviced and non-serviced, or in the case of companies, auto-serviced areas.
- If production sites are located on the periphery of metropolitan areas, commuting distances may grow. In such cases, employees will be faced with long commutes on congested roads or in overcrowded buses. Moreover, difficult traffic conditions could cause an increase in the time and energy required to commute if no efficient and effective public transportation systems are in place.

However, such positive consequences of Industry 4.0 for urban development will not come about automatically. The following examples serve to illustrate some of the potential adverse effects:

- Under certain circumstances, Industry 4.0 – like traditional industrial production – may result in urban sprawl. A location on the periphery of overcrowded urban metropolises may be more attractive for companies as land prices are much lower and freight transport to and from the location is much easier compared to a central location. Moreover, traditional planning thinking and zoning regulations may not permit a mixture of industrial and other land uses and may restrict industrial sites to the outer parts of a metropolitan area.

These examples show that Industry 4.0 and its potential positive impacts are highly dependent on appropriate framework conditions and smart planning. Re-examining existing urban development strategies is therefore indispensable in most countries. It is necessary to undertake a reform of urban development and planning paradigms, possibly supported by international stakeholder dialogues. Strategically-oriented modern urban planning practices that directly involve all the relevant stakeholders may help to deliver the potential urban and environmental dividends of Industry 4.0. The BMZ and GIZ should place special emphasis on improving the framework conditions in order to enable the potential benefits of Industry 4.0 to be fully realized.

A direct link should be established with the German “National Platform City of the Future” (NPZ, Nationale Plattform

Zukunftsstadt) and the respective Strategic Research and Innovation Agenda. The BMZ and GIZ could strengthen the international dimension in this regard. As far as India is concerned, an interesting link could be established with the 100 Smart Cities Program of the Indian Government. In anticipation of the extremely high urbanization rates expected in the coming decades, India is planning to develop 100 smart cities all over the country. Urban retrofits will form part of the program. German development cooperation could contribute its experience in this field and connect the initiative with the results of the NPZ.

4.4 CREATE GOOD PRACTICE EXAMPLES – LEADING THE WAY TO INDUSTRY 4.0

There is a need and opportunity to promote Industry 4.0 in developing and emerging countries in order to keep up with developments in e.g. Germany, Europe, China and the USA. Joint initiatives could be undertaken in selected manufacturing sectors such as automotive, microelectronics, IT, pharmaceuticals and food processing in order to explore the opportunities for Industry 4.0 technologies, consult industry with regard to appropriate technologies and their introduction, establish transfer projects and create good practice examples. Also good practice examples related to cities should be developed, and experience with them should be nationally and internationally exchanged. Advanced Manufacturing, logistics and urban development should become a focus of attention for joint cooperation activities. The creation of international peer-to-peer networks among cities and between cities and other institutions could be a first step to foster international exchange and joint action.

As good practice examples cannot be established everywhere at the same time, one approach would be to start with one carefully chosen example agreed upon by all the relevant parties. It should include the most important aspect of Advanced Manufacturing: intelligent production

controlling the production processes by Cyber-Physical Systems and incorporating the appropriate Industry 4.0 interfaces/standards between the business, production, and logistics levels, and it needs to include several tiers of suppliers, among them also MSMEs. India could be a suitable country for establishing a good practice case, as

- there are many links with German companies, especially in the field of Industry 4.0-related industries; these could be helpful in creating a solid cooperation structure;
- there is close cooperation between acatech and INAE which could be made use of for identifying relevant cases, accompanying the establishment and development of the good practice case and providing analytical expertise during the process;
- the current implementation of the Indian National Manufacturing Plan provides a good basis for cooperation; it promotes modernization of the country's industrial production with special emphasis on support for MSMEs;
- there is already a signed memorandum of understanding between German and Indian ministries (MOUD and BMUB) with regard to urban development; this could be used as an entry point for mobilizing additional engagement on the German side, including the provision of small starting funds in connection with urban issues.

The good practice example should be geared towards facilitating Industry 4.0-based production and logistics processes among a small set of MSMEs, as well as supporting the development of favorable framework conditions in a small or medium-sized Indian city:

- On the company side: automation processes and Industry 4.0-based workflows should be established. It will be especially important to address employment issues, e.g. regarding the quantity and quality of employment in an Industry 4.0 context. Any recommendations should be informed by the quality of growth approach.

- On the urban development side: it will be important to address green urban economy and sustainable urban development issues. This includes smart infrastructure and logistics strategies, the compact city and city of short distances concepts, and integrated urban design patterns, e.g. the application of mixed-use development schemes for environmentally-friendly industrial production facilities, scrutiny of current plans and regulations and urban governance including participation in and transparency of land use policies and decisions.

The good practice example should be accompanied by Industry 4.0 discussion fora and standards activities. These could be used to reflect progress, discuss bottlenecks and evaluate solutions. They would also contribute to

dissemination of the results. Moreover, this would generate valuable experience for the Indian 100 cities program.

Suitable partners on the Indian side could include INAE, the National Innovation Council, CII and FICCI, as well as the Indo-German Chamber of Commerce. On the German side, there is scope for cooperation between the BMZ/GIZ and the BMUB. acatech could be instrumental as a partner and link between the German and Indian implementation structures, providing Industry 4.0 expertise, networking capacity regarding the involved industries and interdisciplinary research capacity relating to the knowledge to be generated through the good practice case. If successful, the Indian case could become a good practice example for similar cases in other countries.

5 APPENDIX

Table: Potentials and challenges of the nexus between advanced manufacturing (AM) and urban development
(Source: Müller/Schiappacasse 2015)

OPPORTUNITIES	CHALLENGES
Urban economy	
<ul style="list-style-type: none"> - Competitiveness of cities may be enhanced through core functions and pioneer establishments related to advanced manufacturing. - There may be additional opportunities for new entrepreneurial activities and small scale enterprises, especially unconventional and creative ones, to connect with larger companies, and to offer new or better services to them. This may lead to more inclusiveness, economically and socially. - Urban economy may benefit from an increase of advanced manufacturing companies: taxes, income generation, multiplier effects, supply chain, etc. - Specialization may make better use and enhance local development potentials. 	<ul style="list-style-type: none"> - Competition may become stiffer as companies have more locational choices due to their shrinking dependence on local production factors. - Integration into advanced manufacturing value creation chains may contribute to socio-spatial disintegration within cities (between those groups and areas which are linked with and those which are not linked with advanced manufacturing); growing social segregation as well as rising disparities between urban districts may be among the consequences. - Specialization may lead to higher economical and development vulnerabilities and risks and it may diminish resilience in case of crisis. - Good urban governance and fruitful cooperation between stakeholders (state, business community) are necessary and crucial factors for successfully raising competitiveness. This is not easy to achieve.
Urban-regional development	
<ul style="list-style-type: none"> - Enterprises become, to a higher degree than today, multi-locational entities. - Individual locations of companies may take over more specialized and focused functions in value creation chains. - AM may diminish the companies' dependency on locational production factors. It may enlarge degrees of freedom regarding the sizes of their enterprise units and production facilities as well their locational choices. - Location factors will be re-defined. Also remoteness will be re-defined. Formerly "remote" areas have more equal chances to compete successfully. - Competitiveness of regions and urban-regional development may benefit from advanced manufacturing. - Regional development may profit through regional value-added production, specialization, additional income generation, regional ancillary industries and services, multiplier effects etc. 	<ul style="list-style-type: none"> - The availability of knowledge creation institutions (universities, research institutions), research and development activities, for example within companies, and interest of companies in regional connections are important prerequisites. - AM strategies are helpful, like smart specialization or urban (economic) development strategies. These require respective initiatives by the public and private sectors. - AM may widen (inter-) regional disparities (and those between cities), that is those which are and those which are not integrated. Specialization may lead to higher risks for regional development.
Value creation	
<ul style="list-style-type: none"> - AM may enhance production and enlarge local and regional value creation chains. - AM may create new opportunities for local regional companies and the informal sector. 	<ul style="list-style-type: none"> - Experience shows that in many cases AM puts more emphasis on international orientation and worldwide integration than on regional embedment.

OPPORTUNITIES	CHALLENGES
Integration and networking	
<ul style="list-style-type: none"> - AM leads to more networked economic structures and processes. Industrial production will be more and more characterized by multi-locational networks. - AM furthers the creation of dynamic and flexible enterprise networks. - AM facilitates related companies to associate for a given time span and to form temporal virtual production or service clusters. - AM manufacturing raises the international inter-connectedness and visibility of cities and regions. 	<ul style="list-style-type: none"> - Networking has high transaction costs and investment (for example time, efforts, personnel). - Network access may be difficult. To a high degree, it depends on decision making by company involved in AM. - Interests of companies and local/regional stakeholders may be different (for example orientation on competitive production on the one hand, and socio-spatial integration on the other).
Knowledge creation	
<ul style="list-style-type: none"> - AM may contribute to raising the educational level of a city as it requires a well-qualified labor force. - AM may contribute to facilitating the establishment and strengthening of universities and research facilities. - AM may support public-private partnerships for knowledge based urban and regional development. 	<ul style="list-style-type: none"> - AM may contribute to social exclusion by making the access to knowledge creation for certain groups of society (for example urban poor) even more difficult.
Socio-economic development	
<ul style="list-style-type: none"> - AM may contribute to creating new jobs and more income opportunities for the urban population. - AM may contribute to the formation or stabilization of a strong middle-class population. - AM may contribute to poverty alleviation through the creation of additional jobs in the industry and the service sector which are more accessible for the urban poor. 	<ul style="list-style-type: none"> - AM may contribute to the loss of (especially less-paid and less-qualified) jobs through rationalization and automation. - AM may restrict job opportunities of the urban poor and the less-qualified. Thus it may contribute to increasing poverty.
Technical infrastructure	
<ul style="list-style-type: none"> - AM may support better urban infrastructure, for example digital and transportation infrastructure. - AM may have positive influence on logistics. 	<ul style="list-style-type: none"> - Weak and un-coordinated planning and implementation may contribute to severe deficits regarding the provision and reliability of infrastructure. - Digital infrastructure may only be provided on demand to those who request and pay for it, thus excluding a large part of the population, especially the urban poor. - Due to inadequate availability of funds and limited fund generating capacity of funds on the one hand and high investment needs, it may be difficult to put the adequate infrastructure in place. - The speed of urban growth may override the capabilities to establish necessary infrastructure thus widening the gap between serviced and non-served (or in the case of companies: auto-served) areas. - Cyber security may be difficult to be established.

OPPORTUNITIES	CHALLENGES
Environmental effects	
<ul style="list-style-type: none"> - AM will lead to cleaner production and more energy efficiency through sensor technology, high precision control and real-time information. - Material consumption and waste will be reduced. - AM will make a contribution to climate change mitigation. - AM may require less storage capacities due to real time information processing. This may result in less land "consumption" for industrial purposes. - Smart products may be easier recycled. This reduced the amount of waste. 	<ul style="list-style-type: none"> - There may be rebound effects. As production sites may be located at the edge of the city or metropolitan area, commuting distances may grow. Because of difficult traffic conditions, time and energy consumption through commuting may increase. - Production sites may be designed as to deal with a variety of difficulties, for example regarding infrastructure provision. This may lead to increased land "consumption" by industry. - Companies may want to secure safe infrastructure provision at their production sites and install basic infrastructure by themselves. This may lead to an un-coordinated and increased consumption of water and energy as well as to environmental damages in general. - Real time production requires just-in-time delivery. This may lead to higher pressure on transportation. More trucks become mobile storage facilities (like in just-in-time production).
Urban structures and land use	
<ul style="list-style-type: none"> - Modularized production allows that individual manufacturing entities become smaller. - AM may facilitate more mixed urban structures through the enhanced possibilities of environmentally friendly integrated "urban production" (for example with management units, design offices or clean production sites within or close to housing areas). - AM may have positive effects on the realization of the concept of the "city of short distances". - Synergies of more mixed urban functions may be used. - This may also bring back life to formerly depressed urban areas (urban retrofit). 	<ul style="list-style-type: none"> - There may be more new urban development outside or on the edge of cities due to better and less expensive availability of land. This may contribute to increased urban sprawl. - Difficult transportation and logistics issues may make it advisable to locate production sites at the edge or outside of existing cities. This may be counterproductive to the concept of the principles of the "city of short distances".

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LIST OF ABBREVIATIONS

4PL	Fourth-Party Logistics
acatech	National Academy of Science and Engineering
AGPS	Assisted Global Positioning System
AM	Advanced Manufacturing
AMT	Advanced Manufacturing Technologies
BITKOM	Bundesverband Informationswirtschaft, Telekommunikation und neue Medien
BMBF	Bundesministerium für Bildung und Forschung
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit
BMWi	Bundesministerium für Wirtschaft und Energie
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung
CII	Confederation of Indian Industries
CO₂	Carbon dioxide
CPS	Cyber-Physical Systems
DEG	Deutsche Investitions- und Entwicklungsgesellschaft
ERDF	European Regional Development Fund
EU	European Union
FICCI	Federation of Indian Chambers of Commerce and Industry
GDP	Gross Domestic Product
GE	General Electric
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
INAE	Indian National Academy of Engineering
ICT	Information and Communication Technology
ICLEI	ICLEI-Local Governments for Sustainability
IPR	Intellectual Property Rights
IOER	Leibniz Institute of Ecological Urban and Regional Development
IOT	Internet of Things
IT	Information Technology
JICA	Japan International Cooperation Agency
KfW	Japan International Cooperation Agency
MOUD	Ministry of Urban Development
MNC	Multinational Companies
MSME	Micro, Small and Medium Enterprises
M2M	Machine to Machine
NIC	National Innovation Council, India
NMCP	National Manufacturing Competitive Programme
NPC	National Planning Commission, India
NPZ	Nationale Plattform Zukunftsstadt
PEF	Product Environmental Footprint
PLC	Programmable Logic Controller

RFID	Radio Frequency Identification
R&D	Research and Development
SDGs	Sustainable Development Goals
SME	Small and Medium-sized Enterprise
SMLC	Smart Manufacturing Leadership Coalition, USA
SWOT	Strengths, Weaknesses, Opportunities and Threats
UN	United Nations
USA	United States of America
VDMA	Verband Deutscher Maschinen- und Anlagenbau
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie

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