Pyka *Journal of Open Innovation: Technology, Market, and Complexity* (2017) 3:27
DOI 10.1186/s40852-017-0079-7

Journal of Open Innovation: Technology, Market, and Complexity

RESEARCH

Open Access

# Dedicated innovation systems to support the transformation towards sustainability: creating income opportunities and employment in the knowledge-based digital bioeconomy

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## Abstract

In order to counter something to the most thrilling challenges of mankind at the beginning of the twenty-first century, production and consumption systems need to transform towards sustainability. We argue that the knowledge-based bioeconomy and digitalization are two promising technological approaches which require to be thought together in order to contribute to the transformation and to trigger the required technological dynamics. However, such a broad transformative process requires a participation of all societal stakeholders. Innovation systems in principle offer a framework for policy designs supporting the transformation, but they need to be extended to include the direction towards overcoming the lock-in in oil-based economic activities and mass consumption. For this purpose, we introduce the idea of a Dedicated Innovation System, which takes care of potential inertia due to the interest of established (oil-based) industries and consider the economic opportunities raised by social and responsible innovation. The transformation process will likely compensate for decreasing jobs in traditional sectors, which are increasingly replaced by robotics and artificial intelligence. The knowledge-based digital bioeconomy is likely to generate the emergence of new sectors with new employment opportunities, e.g. in periphery regions or in the emerging sharing-economy sector.

**Keywords:** Dedicated innovation systems, Transformation, Digitalization, Bioeconomy, Innovation

## Introduction

In their 2015 book "The Triple Challenge for Europe: Economic Development, Climate Change, and Governance", Fagerberg et al. (2015) stress the interlinked character of the most severe economic problems – sustainability, unemployment and a dedicated future-orientation in policies. Economies confronted with crisis and stagnation can no longer apply traditional instruments to return to economic growth and prosperity without bearing the cost of irreversible damages of the environment. A simple *keep it up* is no longer possible. As a last resort to this thrilling global problem a fundamental transformation of economic production systems is suggested, which pushes economic development on a green growth trajectory (Mazzucato and Perez, 2015).

For the required transformation of global production and consumption systems, which targets the twentieth century *lock-in in carbon-based technologies* (Unruh, 2000) two broader technological concepts play outstanding roles:

(1) Digitalization and with it artificial intelligence and robots are supposed to increase massively the efficiency in production, thereby reducing the consumption of resources and frequently even completely replacing physical output by $CO_2$-neutral digital output (*dematerialization*),

(2) and the so-called knowledge-based bioeconomy which replaces in many applications oil-based by bio-based materials. The knowledge-based bioeconomy focuses on a sustainable production and processing of biomass into a range of products encompassing food, health products, fiber and industrial products as well as energy. Basically, biomass is supposed to substitute for crude-oil. Renewable biomass includes any biological material from agriculture, forestry and animal-farming as a product in itself or to be used as an input in further production.

In order to set economic development on a sustainable development path, both technological trajectories need to merge into the knowledge-based digital bioeconomy. This way synergies are created which foster the required changes in production as well as consumption.

However, for a fundamental transformation, technological ingredients alone are not sufficient: To steer the transformation successfully, societies around the world have to place stronger emphasis on different types of innovation, which includes besides technological, also social, political and ecological innovations.

Social awareness of an endangered sustainability of production systems is not new. Since "The Limits of Growth" was published by the Club of Rome (Meadows et al., 1972), it is evident that fundamental changes are required to guarantee human survival on planet earth. In economics, on a purely theoretical level, two fundamentally different solution strategies for this thrilling problem can be distinguished: (i) conservation of resources by the abstinence of growth and (ii) decoupling of growth and resources employment. The supporters of the first approach (Blewitt and Cunningham, 2014, Kallis et al., 2014) summarized under the headings of abstinence and downscaling follow the quantitative orientation of mainstream economics and claim a renunciation of a way of life that is based on consumption and increasing resource intensity. To reach a sustainable production the quantity of the employed resources has to be decreased massively. The second approach, embedded in Schumpeterian economics with its qualitative view on economic development, strongly emphasizes that innovations, market forces and structural change are not part of the problem, but have to be part of the solution. Creative solutions are able to fundamentally reform our economy in the sense of sustainability, thereby supporting the achievements of the UN objectives towards sustainable development (UN, 2015) and ensuring growth and development at the same time (Mazzucato and Perez, 2015). It is clear that this transformative direction of innovation processes cannot be expected to happen without a concerted action of all actors in an economy, namely firms, consumers and policy makers, which together constitute the actors of an innovation system.

Since quite a while, leading researchers in innovation economics (Dosi et al., 1988; Lundvall, 1992, 1998; Nelson, 1993) emphasize the systemic character of innovation. So-called *innovation systems* consist of different actors (companies, research institutions, political actors, consumers etc.) and linkages between these actors (flows of goods, R&D cooperations, knowledge transfer, user-producer-relationships etc.) as well as institutions, which all are to be coordinated in this transformation. The linkages are required to ensure mutual learning and knowledge development in order to explore potential paths of the sustainability transformation. Such systems are characterized by their dynamic and co-evolutionary nature and thus are enormously complex. A transformation towards sustainability requires coordination and adaptive management of such a system, in particular of the interactions, of mutual learning processes to spur cross-fertilization between different knowledge fields and most important to develop competences to deal with fundamental uncertainty (Knight, 1921), which is much higher compared to an *exploitation-oriented* innovation system in non-transformative periods. As a heuristic for explicitly incorporating the systemic (co-)creation of normative and transformative knowledge by all relevant agents in innovation systems, we adopt the new notion of ***D****edicated* ***I****nnovation* ***S****ystems* (DIS) (Pyka, 2017). DIS explicitly go beyond technological innovation and economic growth and allow for paradigmatic change towards sustainability: They are "dedicated" to foster the joint search for transformative innovations. In other words, the proposed conception of DIS implies that the predominant focus of innovation systems on economic competitiveness needs to step back behind the global societies' imperative of sustainability.

The focus of DIS is systemic innovation by continuously re-thinking highly uncertain and path-dependent developments. It calls for experimentation and cross-fertilization, and may be hindered among others by incumbent power relations, network structures, and free-riders. Just as responsible innovation (e.g., von Schomberg, 2012, 2013; Stilgoe et al., 2013, Schlaile et al., 2017b) seeks to involve societal demands and ethical requirements in innovative activities, a dedicated systemic innovation needs to take all relevant actors on board for negotiating goals and solution strategies. This approach, which targets radical transformations of existing institutions and routines, would surely not reach the required high priority on a policy and research agenda if an established research community steered by current politics in line with the powerful incumbent industries takes the lead – simply because the currently powerful usually have little interest to change anything and run into danger to replace themselves. Therefore, DIS requires besides technological innovation a smart integration of social innovations to increase the extent of positively affected citizens and thereby their willingness to contribute to the transformation in order to overcome the inertia of the oil-based paradigm.

A particular opportunity for an increasing involvement is endogenous to the knowledge-based bioeconomy: Due to the high importance of the production of biomass, the knowledge-based bioeconomy is full with opportunities for periphery agriculturally dominated areas, which so far did not participate sufficiently in economic growth and development. The discovery of these opportunities will strongly support the breadth of supporters. Furthermore, as a transformation towards sustainability will not work without fundamental structural changes, DIS require a vision, which takes care of the non-linearities, uncertainties and unavoidable surprises of complex development. A linear extrapolation of the current status very likely will generate devastating expectations, which finally prevent the desired transformation. The discussion on the future of labor which increasingly will be replaced by robots and artificial intelligence (e.g. Rifkin, 1995) certainly has such a potential to decrease the broad acceptance of a DIS. Such a discussion is based on linear extrapolations in a standard textbook manner ignoring qualitative changes emphasized by Schumpeterian innovation economics.

In this paper we will outline the idea of DIS together with the application of a knowledge-based digital bioeconomy. Furthermore, the effects of digitization on labor markets are analyzed by taking care of structural changes. For this purpose, in section 2 the role and meaning of DIS is described. Section 3 deals with social innovation and the possibilities of innovation networks to create new opportunities in periphery regions. Section 4 highlights the connections between digitalization and the knowledge-based bioeconomy and emphasizes the meaning of structural change for employment projections. Section 5 summarizes and develops further research questions.

## Dedicated innovation systems (DIS)

Processes of change can be either of incremental nature by simple improvements or can be more fundamental and connected with structural changes (Pasinetti, 1981, 1993), i.e. the appearance of new and/or the disappearance of old industries. Incremental technological changes are based on existing technologies whereas radical technological changes question major existing production processes. They might lead to incisive changes of the global production system in the sense of creative destruction (Schumpeter, 1942).

Concerning the transformation towards sustainability we are confronted with a fundamental transformation of production systems: overcoming the lock-in of in fossil fuels (Unruh, 2000) and establishing a bio-based and digital knowledge-based economy at the same time (Pyka, 2017). This transformation process is, without doubt, radical, qualitative and effective in the long-run and asks for a dedicated innovation system linking all actors in the supply, demand, policy and science sector. This includes the further development of a model of economic growth and development capable to capture structural change in transformation processes, reflecting on the time-paths of economic development and explicitly allowing for the inclusion of feedback effects between environment and economic production. Furthermore, innovation systems theory has to be extended to capture the particularities of technological and social innovation as well as normative issues applicable to industrialized as well as developing economies (see Schlaile et al., 2017a).

It was already in his work "Business Cycles", published in 1939, when Schumpeter (1939) revitalized Kondratieff's theory of long waves in order to explain that fundamental transformation processes are regular processes in the long-term view of economic development. His illustration, which is characterized by its discontinuous nature is famous: "Add successively as many mail coaches as you please, you will never get a railway thereby" (Schumpeter, 1934, p. 64). Now, at the beginning of the twenty-first century, another paradigmatic change is looming, being characterized, however, by a major difference to previous transformations: whereas previous cycles were driven by technological bottlenecks and their overcoming, human mankind in the twenty-first century has to restore environmental sustainability of economic activities. For the fundamental transformations since the beginning of the industrial revolution, the emission of greenhouse gases was not considered as a problem. However, latest since the 1990s the knowledge about manmade climate change can no longer be ignored and adds an imperative (***the dedication***) on the next fundamental transformation. Today, literature provides many alternative terms for changes covering the global production system, for instance Freeman (1991) and Dosi (1982) call them techno-economic paradigm changes. All authors highlight the technological, economic and social confrontations resulting from profound changes in the economic systems over time. These changes often question all established previous production approaches. For example, the twentieth century triumph of cars was not only caused by the technology of combustion engines, but several complementary developments, which include apart from a package of mutually dependent technologies (e.g. petro chemistry, assembly line production) numerous infrastructural developments (e.g. road structure, filling station network), behavioural changes (e.g. suburbs and commuter flow, shopping malls outside the city) as well as institutional changes (e.g. spatial planning and commuter allowance etc.). The old paradigm will not be replaced by the new one until all these elements interact, or at least reach a critical mass to trigger further changes. This example highlights the need for a comprehensive DIS, which includes all societal actors.

Traditional approaches of economic growth are both short-run and quantitative oriented and do not allow for a consideration of long term knowledge driven structural changes (Castellacci and Natera, 2016; Foster, 1998; Dutrénit et al., 2016, for a most recent overview see Nelson et al., 2018). As an alternative Schumpeterian model, Saviotti and Pyka (2004) introduced a model in which economic growth is generated by the emergence of new industries emphasizing the co-existence of different productive sectors (including industries, primary sector and services) as well as the emergence of new and the decline of existing productive activities. Recent econometric research applying new tools from complexity science give strong evidence for the role of this economic diversification over time for economic development (Hidalgo and Hausmann, 2009; Hausmann et al., 2014, Hartmann et al., 2015, 2016).

We emphasize that the connection between economic growth, development, social inclusion and sustainability is strongly determined by national innovation capabilities and absorptive technological capacities (Abramovitz, 1986; Acemoglu et al., 2005; Cassiolato and Lastres, 2008; Fagerberg et al., 2010; Katz, 2001; Lundvall et al., 2002; Lundvall, 2005). To install sustainable production systems, a major knowledge-driven transformation is required at the beginning of the twenty-first century (Schot, 2016). To complement, we need to analyze how the systemic innovation capabilities and absorptive capacities of the countries determine their ability to adopt new technologies and transform their economy into a knowledge-based bioeconomy (Urmetzer and Pyka, 2017, Castellacci and Natera, 2016). Obviously innovation systems are characterized by national particularities and may differ across countries (Dutrénit and Sutz, 2014). In particular, innovation systems of industrialized countries and developing countries are strongly different. Among others, the role of social innovation differs substantially, university-industry links are organized differently and education systems focus on different competences and different target groups.

The underlying principle of the knowledge-based digital bio-economy is substitution of carbon-based materials and energy with bio-based materials and energy (German

Bioeconomy Council, 2015), or even dematerialization (Seidler and Bawa, 2009)). Most technologies of the bioeconomy heavily build on biomass as a major resource for sophisticated new production processes. From this follows, that the transformation towards a knowledge-based bioeconomy offers particular opportunities for periphery regions with a dominant specialization in agriculture. Again, one cannot assume that these opportunities will be automatically realized. For the sustainability transformation, a confinement to technological innovation is not sufficient. Strong impacts are to be expected from social innovations (Hanusch and Pyka, 2013) which involve all social groups and allow them to participate in income development, thereby improving the income distribution and strengthening social resilience. Without innovation networks connecting for instance farmers, companies and research laboratories many of these promising new paths are likely to remain undiscovered. With the right innovation networks the prerequisites for social innovations are generated, which in particular support the development in the so far economically less dynamic periphery regions. Most important, social innovations can make a major contribution to rural development and promote economic resilience in these regions by strengthening cooperative behavior (Moore and Westley, 2011). As a consequence, today lagging rural regions are equipped with new opportunities for sustainable economic development. The concept of social innovation emphasizes the importance of active citizenship in innovation, covering social demand and creating new social relationships (Heeks et al., 2014). Therefore, society benefits as a whole and receives new impetus to improve and to develop.

To achieve the sustainability goal, the entire breadth and depth of all value-added chains is targeted. The exploration of economic complementarities in terms of cross-fertilization of different knowledge fields plays an outstanding role and comprises besides directly bio-based technologies also other technologies, most important digitalization: physical products and energy intensive services can often be replaced by bits and bytes (e.g. paperless office, digital newspapers etc.). Without doubt, a future-oriented strategy cannot dismiss the potentials offered by digitalization and automation, in particular robotics and artificial intelligence. Saving resources is not only an issue of the supply side, but will be also most important on the demand side. Almost needless to state, that also consumers play a key role in these networks and will have to support the transformation. No innovation will survive without consumers willing to adopt it. Also, changed consumption patterns like sharing-economies will accelerate the transformation (Perez and Marin, 2016) and reduce massively consumption of resources. Here we find one (of many) strong complementarity between the knowledge-based bioeconomy and digitalization technologies to organize an efficient and acceptable larg sharing- economy.

However, on a first view, here a strong conflict with the employment goal might emerge because many jobs and activities might be replaced by robots in the future. A negative forecast on employment and related on income distribution can be a massive obstacle in the desired transformation. Historical reflections seem to corroborate a more optimistic perspective. In the past, industrial revolutions triggered structural transformations, which, after recovering from initial technological unemployment, have brought mankind merely frictional unemployment, and prosperity rather than poverty, and it remains to be seen whether it is different this time (Mokyr et al., 2015). From an historical perspective, we may be optimistic that demand for new products develops, new sectors emerge, new skills are required, and jobs are created. Possibly, we are just entering a period of transition with temporary technological unemployment. This important discussion will be taken up again in section 4.

The knowledge base of an economy which is the aggregate outcome of the underlying innovation system, is of utmost importance. Numerous individual knowledge fields driving the transformation are already identified, e.g. synthetic chemistry, process engineering, genetic engineering, agriculture, food technology or informatics. Understanding the dynamics of these knowledge fields and the possibilities of their recombination with other knowledge fields is essential. In many cases, linkages of different knowledge fields are responsible for the emergence of immense new technological opportunities: bioinformatics as a new industry has been initiated by merging two so far unconnected knowledge fields, namely database technology and molecular biology. As a consequence, today we see Big Data applications to boom in many different sectors. This also affects the composition of individual sectors where a coexistence of large diversified companies and small high-specialized technology companies is a likely solution. Because the fusion of different knowledge fields is confronted with fundamental uncertainty, governmental innovation policies are required, which complement firm based research activities. The analysis of these knowledge and network dynamics allows to identify development trajectories and sectors, which are critical to close existing knowledge gaps and to build bridges between so far unconnected knowledge (Burt, 2004; Zaheer and Bell, 2005). Knowledge development and diffusion of relevant bioeconomic and digital knowledge depends on dynamic innovation networks (Pyka, 2002) in which different actors share and jointly create new knowledge.

A main effect of the transformation towards a knowledge-based digital bioeconomy will be observed on the sectorial level in the form of pronounced structural changes. Although neither digitalization nor the bioeconomy does represent a well-defined industrial sector, but are characterized by their cross-sectional character, the application of the theory of industrial life cycles (e.g. Klepper, 1997) is helpful to grasp this transformation: The digital and bioeconomy transformation will trigger the emergence of new sectors e.g. in the fields of bio-plastic, waste management, bio-refineries or the sharing-economy. Additionally, the existing industries will be affected, some of them will be replaced and simply disappear, some others will receive new momentum as to be expected in the fields of battery technology and pharmaceuticals. Adjustments of old and development of new institutions (e.g. the Renewable Energy Act, the Greenhouse Gas Emissions Trading Law etc.), of consumer habits and the emergence of new educational opportunities in terms of co-evolution will accompany these processes.

To summarize, DIS are complex adaptive systems composed of industrial, scientific, political, fiscal, and civil society actors as well as institutions and the links between the actors that provide a creative environment for mutual learning and knowledge creation in the pursuit of socially desirable and sustainable innovation. Such systems are expected to be capable of shaping (and accelerating) processes of transformations towards sustainability. In this regard, DIS depart from their conceptual predecessors, the so-called National Innovation Systems (NIS): Whereas NIS (as well as regional and sectoral innovation systems) focus on generating competitive advantages on a national or regional level through innovation and technological progress, DIS aim at governing open-ended processes of paradigmatic change towards economically, socially, and environmentally viable systems, i.e. sustainable systems. The design of DIS requires participatory approaches such as responsible and social innovation that must be seen as complementary to the required scientific and technological advances. On the basis of such approaches, individuals within the DIS are empowered to become co-responsible citizens, e.g., by shaping production systems and changing consumption habits. The inherent complexities of transformation processes as well as globally different initial conditions are responsible for the absence of an optimal and universal “one size fits all” DIS suitable for all societies, economies, or cultures. Instead, transformation towards sustainability requires varieties of DIS (Urmetzer and Pyka, 2017) in order to account for different geographical, socio-economic, political, and cultural characteristics. In particular, in less developed economies as well as in periphery regions, the opportunities of the knowledge-based bioeconomy ask for social innovations to create new employment and income opportunities organized in innovation networks. The following section will introduce a few cases from Mexico which exemplarily highlight the rich potential of this strategy.

## Generating opportunities for participatory development with social innovations

The following cases show the important meaning of comprehensive innovation networks encompassing universities, research centers, firms, public agencies and rural population for the setting up of a DIS (for an example from Brazilian Sugar cane processing, see Scheiterle et al., 2017). Technological innovations, either incremental or radical, are to be embedded in social innovations, which generate participative and inclusive growth and strengthen social resilience. The identification and selection of the following cases resulted from a cooperation between Universidad Autónoma Metropolitana (UAM) and the University of Hohenheim in the DAAD funded strategic network Bioeconomy (BECY). More details on some of the cases can be found in Torres et al., 2014.

The innovation farming system in Mexico is highly heterogeneous; high-tech sectors (e.g. tomatoes and vegetables production) coexist with traditional and labor intensive sectors (Dutrénit et al., 2016). Low productivity levels in traditional sectors ask for the application of new scientific and technological knowledge, but also new ways of organization. There is wide room for the introduction of social and inclusive innovations supporting sustainable development and biodiversity preservation. Previous studies show the importance of establishing new links between two actors in this innovation system, namely university researchers and producers and farmers. The success depends on the learning capabilities of the rural population and the critical role played by some innovation bridges and transfer organizations in promoting and supporting new relationships (Vera-Cruz and Dutrénit, 2016; Dutrénit et al., 2012; Ekboir et al., 2009). In the following paragraphs some exemplar cases are briefly described, to explore various types of bioeconomies, suited for the combination of fostering sustainability and social inclusion.

The first example deals with the implementation of an entrepreneurial attitude into the young population in rural Mexico. A local development agency with the aim to support social entrepreneurship in the rural area started working with young farmers. The aim was to develop their entrepreneurial abilities in early stages of their lives. Learning processes generate most promising results and strengthen productive, technological, and entrepreneurial competences with younger participants. The project RANCH EGGS was designed in 2007 and consists of forming groups of children between 12 and 18 years old, which together produce eggs for self-consumption and commercialized surplus. Already in 2008, in total, 65 children from seven periphery communities participated, and several poultry units were built up. Over time the number of participants and the amount of production was strongly increasing. Three years later, in 2011, 240 children in nine communities participated. And in 2012, 274 participants from 11 communities produced in total 460.000 eggs. In 2014, 427 young farmers produced on average 1400 eggs per farm (more than 500.000 eggs in total) and they keep 3.600 hens. With this production size substantial new income opportunities were generated and the young entrepreneurs sell their eggs today to hotels and restaurants. RANCH EGG is a convincing example of how entrepreneurial attitudes create new income and strengthens social resilience – this promising result was achieved with relatively simple instruments, which create new links among young farmers and the development agency in order to foster the knowledge transfer and help to build up entrepreneurial competences (Sampedro and Vera-Cruz, 2016).

The second example shows how bioeconomy applications can strengthen social resilience in periphery regions, which suffered from migration because of missing income opportunities. Stevia is a sweetener plant with growing production all over the world, which can be used as a sugar substitute. Several applications, mainly in the food and beverage sector are already existing and the respective industry is interested in developing a product portfolio allowing to meet the demand of consumer for healthier products. The Mexican agricultural company GAVIA specialized in the production and technological development of different hybrid varieties of stevia and a researcher of UAM Xochimilco's 'department of human and his environment' started a research project to develop and adapt stevia plants to different Mexican regions, in particular close to the U.S. border. The company's development was heavily supported by this university-industry cooperation. The university as the main partner provided scientific and technological knowledge, training for technicians and involved students in this research on processes around the production, marketing and application of stevia. Meanwhile, the fast growing company GAVIA has developed an innovation network which integrates 11 firms. Each firm is specialized in different parts of the stevia production: development and production of fertilizers, management of organic products, pest control, commercialization, human resources training, research and development. With these activities and the Stevia production, new income opportunities and employment were developed, which finally stopped the migration of young males into the U.S. We take this as a successful example to illustrate the benefits of academic-industry linkages and how knowledge production drives economic growth and development in specific Mexican bioeconomy sectors.

The third example from Mexico City deals with social entrepreneurship which supports the diffusion of a technology which is suited to improve water supply in the city and to create new jobs for craftsmen. The company ISLA URBANA, founded in Mexico City in 2009, is offering a likewise simple technology to collect rainwater. The company's system of rainwater harvesting and its adaption to the regional economic context and infrastructure, ranges from simple systems to treat water for irrigation use (domestic activities) to systems that allow conversion into drinking water. Today, ISLA

URBANA operates in various periphery and excluded communities; it uses inexpensive materials and simple equipment (e.g. water tanks acquired in the same communities and developed in cooperation with the community), generating easily manageable technologies appropriated by the beneficiaries. So far, the company has installed more than 2.600 systems with more than 18.500 beneficiaries and 280 million liters of harvested rain water.

The fourth example connects the knowledge based bioeconomy with the generation of new income opportunities in university-industry-farmer networks. The AXOLOTL, an indigene amphibian which lives in the lakes around Mexico City was endangered by the pollution of the city. Therefore, university researchers from UAM developed a process to artificially breed the animal. In this research it turned out that the animal allows for promising applications in dermatological pharmacy, which brings in pharmaceutical companies. Today, local farmers breed the Axolotl in the outskirts of the city and sell the animals to the pharmaceutical companies. Besides the new income opportunities and the positive effect on social resilience, biodiversity is maintained and new biological compounds for pharmacological purposes became available.

The fifth and final example deals with an university-industry-farmer innovation network in engineering. Many of the Mexican inshore waters suffer from pollution by the WATER LILY, which is a pest plant rapidly spreading out on water surfaces and restricting shipping. Process engineers from UAM developed a technology to use the water lily as a resource in the paper and pulp industry. The pest plant is now harvested by local farmers, who sell it profitably to companies in the respective industry. Besides the new income opportunities, this innovation network is responsible for an improvement of the water quality in the lakes, reduces costs of shipping and introduces a new and cheap resource to the pulp and paper industry.

Table 1 is summarizing the five cases illustrated above.

These cases from Mexico are not the result of any national or regional government initiative. They are bottom up processes in self-organized innovation networks which generate special, regional applicable knowledge to locally exploit the potentials from a knowledge-based bioeconomy. They also show the potential of the bio-based transformation to combine technological and social innovation with social resilience. Most important, all the cases are inclusive in the sense that lower income groups in peripheral regions develop new income opportunities and participate in these knowledge

**Table 1** Five cases of social innovation in the Bioeconomy from Mexico

| Case | Innovation Network | Focus | Result |
|---|---|---|---|
| RANCH EGG | Development Agency and Farmers | Building up of entrepreneurial capabilities | Income opportunities, social resilience |
| Stevia | University, Industry and Farmers | Implementing Stevia production and applications using Stevia as sugar substitute | Income opportunities, social resilience, healthier food |
| ISLA URBANA | NGO, local governments and craftsmen | Social entrepreneurship | Income opportunities and an improvement of water supply |
| Axolotl | University, Industry and Farmers | Animal breeding and pharmaceutical application | Income opportunities, social resilience, protecting biodiversity, new biological pharmaceutical compound |
| Water Lily | University, Industry and Farmers | New resource for pulp and paper industry | Income opportunities, social resilience and water cleaning |

driven developments. The emergence of the new sectors within agriculture and mostly in periphery regions displaces established resource- and energy-intensive established productions on a regional level. This exemplarily shows the transformative and structural change inducing power of small dedicated innovation systems. The focus of these DIS is simultaneously on economic, technological, social and ecological improvements.

However, in emerging countries a conflict between economic growth and ecological sustainable development is still dominating the discussion. For a number of reasons, politicians from emerging economies put rather emphasis on traditional industrialization than on bioeconomy technologies and sustainable development. However, knowledge-based and sustainable agriculture or renewable energy sources in Mexico are emerging as drivers of a new path of sustainable development. In particular, knowledge-based and sustainable agriculture can help to connect local farmers to the national innovation system and foster also processes of social inclusion and overcome the inertia of established production systems.

This shows another dynamic effect in the emergence of a DIS: The success of these cases and the debate on climate change as well as the rise of new technologies like solar, wind and biomass energy has strongly supported the interest in the knowledge-based bioeconomy in a wider group within the Mexican society. In particular, new targets for development and STI policies meanwhile changed the policy agenda in the sense of a Dedicated Innovation System. In line, new concepts are emphasized, e.g. sustainable development, awareness of climate change, welfare and social inclusion. As a result, today innovative policy designs are developed to tackle these new targets. Several of the action lines of the National Development Plan of Mexico, approved in 2013, explicitly tackle issues concerning sustainability, climate change and the fostering of bioeconomy related sectors (CONACYT, 2014).

## Employment development and structural change

In this transformation towards sustainability the exploration of economic complementarities in terms of cross-fertilization of different knowledge fields strongly matters. The greenhouse gas and resource saving impact of the knowledge-based bioeconomy are considerably aggravated by the second major technological trend, namely digitalization, which allows for an extension of value chains by increasing the added value in new sustainable production sectors in a CO2-neutral way (e.g., by electric mobility based on renewables, by development of smart grids, reducing transport etc.). For consumption digitalization opens up large opportunities to organize effective sharing-economy platforms, which contribute considerably to saving resources.

In such a process, innovative adjustments in already existing industries as well as the emergence of new and the disappearance of mature industries can be observed. In addition to the substitutive relations of new bio-based industries to traditional oil-based industries, there are numerous essential complementary relations giving further momentum for the transformation process. First, there are the possibilities and application fields of digitalization in a narrow sense. Digitalization allows to replace many oil-based products and energy-intensive services simply by digital products. Simultaneously, digitalization offers a wide range of opportunities by coordinating decentralized and very specialized bioeconomical technologies and processes, such as energy production and distribution (e.g. smart grids). This affects the composition of individual sectors, where a coexistence of large diversified companies and small high-specialized technology companies is a likely solution. Finally, digitalization also offers consumer platforms to efficiently organize 'sharing-economy' approaches. Examples include the development of new products within emerging bio-economic innovation systems, e.g. the stevia, axolotl and water lily cases. In this perspective, innovations require an interplay of actors along value added chains, which might lead to the development of new industries. In the past, for example, the provision of cheap electricity led to the spread of fridges and freezers in private households, which brought innovations in the fields of frozen food and packaging. Similarly, the creation of a ‚Sharing-Economy'may lead to new digital coordination platforms and the creation of sustainable designs by product manufacturers in the bio-economy. Planned obsolescence, a phenomenon wasting resources by shortening product life cycles, would be eliminated this way, and new sectors, for example, in the field of repair and maintenance services are initiated. Important determinants shaping long-term development are networks and clusters. They help to reduce uncertainty and support self-reinforcing effects. Furthermore, social changes and changing lifestyles are both, an expression and a driver of this transformation process (Mazzucato and Perez, 2015).

Besides these complementary effects between digitalization and the knowledge-based bioeconomy, which are critical for a successful transformation towards sustainability, digitalization is strongly connected with changes on the labor market. The analysis of labor market developments again mirrors the two strategies, discussed in the introduction: Economic growth as the cause of the problem or economic growth and development as a contribution to its solution. The following paragraphs build on Vermeulen et al., 2017, and outline briefly the ambiguous discussion between quantitative oriented mainstream labor economics and qualitative oriented multi-sectorial Schumpeterian innovation economics.

Like computerization and – in general – the introduction of ICT before – digitalization, robotization and the introduction of artificial intelligence (AI) are expected to increase the productivity in the sectors of application, thereby substituting for particular tasks, but possibly also requiring the introduction of new tasks to exploit complementarities. Because negative employment effects may hinder a DIS to unfold its transformative power, it is important to envisage not only the direct effects within a sector, but to consider in a holistic way the multi-sectorial interdependences. Generally, the introduction of productivity-enhancing technologies is lowering net employment in the focal sector of application (Rodrik, 2016). There will be technological unemployment, if this loss in jobs is not compensated by the creation of jobs elsewhere (Keynes, 1930). Without doubt, it is the 'narrow focus' on the (loss of jobs in the) sector of application which gives rise to anxiety about mass unemployment.

In line with the multi-sectoral perspective of structural change, our suspicion is that the displaced employees may find jobs in other sectors such that technological unemployment is merely temporary and may thus be considered a special type of frictional unemployment caused by the immobility of labor (in geographic and knowledge space). In the transformation towards sustainability new employment opportunities arise not only in sectors developing, producing, supplying, supporting robotics and AI technology, but also in new emerging sectors, e.g. in periphery regions with new agricultural occupations (see above). These new employment opportunities compensate for unemployment created by application of robotics and AI. Studies that take a more holistic perspective indeed find that there are various mechanisms through which there is a net creation of employment (Stewart et al., 2015; Gregory et al., 2016).

Detailed analyses at the level of (existing) jobs (Frey and Osborne, 2017) and (existing) sectors (Manyika et al., 2013) revealed that many jobs are at risk of being computerized and/or roboticized. These analyses, however, focus exclusively on the sector of application (e.g. manufacturing, and also agriculture) in which there is predominantly labor substitution and thus underestimate the positive effects of complementarities (both on keeping but also generating jobs). In addition, these analyses do not only overlook the generation of jobs in the developing and producing (e.g. robotics technology) and supporting sectors (e.g. component producers), but also disregard the facilitating sectors (e.g. education) and sectors receiving spillovers. Moreover, the static perspective completely ignores the creation of (jobs in) new sectors spawned. We conjecture that in most sectors in the multi-sectoral, structural change perspective, we may see a (potential) increase in demand for labor and thus an increasing employment rate. This is visualized in Table 2.

In general, recent labor economic studies on the impact of robotization and automatization lack a holistic perspective on the economy. There are a few exceptions and indeed these studies come to structurally different conclusions. For instance, in the UK, Stewart et al. (2015) incorporate also complementarities, e.g. increasing demand for labor in supporting sectors such as software engineering, and indirect effects, e.g. enhancement of the output generating more demand for products and lower costs increasing discretionary income. This study finds that technological progress, contrary to the narrow studies mentioned above, continues to create new jobs in (i) generating sectors (e.g. software engineering, scientific research), (ii) complementary sectors (e.g. health care, knowledge-intensive business services, sharing-economy), and (iii) sectors providing discretionary goods and services (e.g. gym, entertainment) (see Stewart et al., 2015). Additionally, in the new bioeconomy sectors a considerable increase in employment figures (as well as self-employment figures) are likely to be expected. Also Gorle and Clive (2013) claim that the introduction of robotics and artificial intelligence contributes positively to employment because of the many new jobs that will be created in distribution, services and new manufacturing applications.

The findings of Stewart et al. (2015) hint towards an ongoing structural transformation in which employment moves from agricultural and manufacturing sectors to

**Table 2** Conjectured effects of employment in the various sectors in the structural change perspective

| Nature New/ existing? | Developing & producing | Supplying & supporting | Applying | Facilitating | Spillover |
|---|---|---|---|---|---|
| Existing sectors | Increasing employment (higher demand) | Increasing employment (higher demand) | Increasing employment for jobs with complementarities; decreasing employment for jobs due to substitution; Possibly increasing employment due to possibly increasing demand | Increasing employment (higher demand) | Increasing employment |
| New sectors in the bioeconomy | Increasing employment | | | | |

service sectors. (And one has to add, back to agriculture with the emergence of a knowledge-based bioeconomy.) Although the knowledge-based bioeconomy is not targeted in the recent studies of employment effects on robotization, the studies are suited to highlight the strong structural effects which accompany the diffusion and wide application of the new technologies. Colin Clark was the first to model this transformation from a society with work primarily found in agriculture, to a society with work primarily found in industry, and now to a society in which most people work in services. For a recent, detailed empirical study on structural transformation, the reader is referred to Herrendorf et al. (2013). A captivating account of this is found in Ford (2015):

"The mechanization of agriculture vaporized millions of jobs and drove crowds of unemployed farmhands into cities in search of factory work. Later, automation and globalization pushed workers out of the manufacturing sector and into service jobs. Short-term unemployment was often a problem during these transitions, but it never became systemic or permanent. New jobs were created and dispossessed workers found new opportunities. What's more, those new jobs were often better than earlier counterparts, requiring upgraded skills and offering better wages".

Schwab (2017) argues that robotics and AI are part of a set of technologies which will give rise to the fourth industrial revolution. As such, mankind may face a structural transformation to a prominent role for a fourth 'broad sector', i.e. the quaternary sector. There are somewhat disparate ideas on what this quaternary sector may comprise, but, obviously, it will host work that robots and AI cannot do, i.e. work revolving around socially intelligent interaction and interpretation, creative intelligence, physical flexibility and dexterity in a dynamic environment, etc. (see Frey and Osborne, 2017). In our perspective, it may very well include besides the entertainment industry (literature, movies/show/series, literature, theater, etc.), journalism, sports, leisure and tourism industry, design and fine arts industry, and handicraft and culinary sector, sectors focusing on self-realization, also the knowledge-based bioeconomy with specialized production of biomass, processing of biomass and new forms of food production like urban farming and urban horticulture as well as the sharing-economy.

As stressed before, we should not look only at existing sectors of application, but take a multi-sectoral perspective so as to prevent underestimating the economic impact. It is in fact quite easy to underestimate the employment creation, because robotics and AI as well as technologies in the knowledge-based bioeconomy are *general purpose technologies*. Assessing the (technological) impact of general purpose technologies is notoriously difficult as (i) technologies only gradually diffuse (and we seem to be only at the onset of this), (ii) directions for further development become clear only ex post, and (iii) complementary investments are required to reap benefits (and often only reveal themselves upon implementation) (Helpman and Trajtenberg, 1998; Bresnahan and Trajtenberg, 1995).

To summarize, in Fig. 1 we discern three scenarios on the effects of labor-substituting robotics and AI on the total employment. The figure compares three different developments of employment figures (blue) and the introduction of robots (red) (vertical axis) over time (horizontal axis).

Firstly, there is the 'end of work' scenario, which likely will prevent a DIS to emerge because of social opposition against technological development producing mass unemployment. In this case, robotics and AI will become so advanced that any jobs,

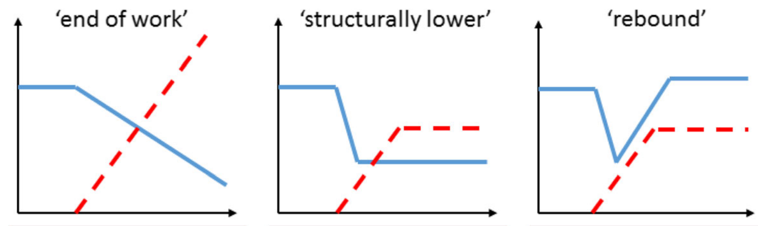


**Fig. 1** Three scenarios on effects on employment (Y-axis) of labor-substituting robotics and AI over time (X-axis). employment/ labor share: Blue, continuous line; capital share: red, dashed line. Own visualization

including those created in new sectors, are soon taken over by technology again. We will end up in this scenario if the rate at which humans can be re-educated and retrained for employment is lower than the rate of technological advancement. Moreover, it requires that the job destroying potential of technology through substitution outpaces the job creating potential of technology through complementarities (MacCrory et al., 2014).

Secondly, in the 'structurally lower' scenario, some jobs are destroyed by robots, but (a proportional part of the) displaced employees can be re-educated to find a job in other and possibly new sectors. One argument in favor of this scenario is that technological advances in new sectors stifle, if education cannot foresee the necessary skilled workers. As such, education in fact moderates the pace of technological progress. Note that the 'structurally lower' levels of employment may also be because the number of hours worked per week may further decline.

Thirdly, in the 'rebound' scenario, after a shock due to the massive structural changes in the transformation process towards sustainability, the level of unemployment returns to a 'regular' rate of frictional unemployment. Just like in the 'structurally lower' scenario, education moderates the pace of technological progress, but employees can catch up faster than technology can progress, in particular they find employment in the new emerging industries. Obviously, in this scenario the emergence of a DIS will find broad acceptance among broad social groups.

## Conclusions

In order to leave the current path (e.g., massive C02 emissions, overconsumption and energy intensive and oil-based production systems) and head towards a more sustainable direction, the world needs fundamental transformations of local as well as global systems, including social, economic, and cultural ones. For this purpose, we have introduced the new notion of Dedicated Innovation Systems (DIS) as an overarching framework for transformations towards sustainability. DIS go beyond exploitation-oriented Innovation systems because they attempt to achieve a dynamic balance between demand driven technology pull, science and market driven technology push, and social innovation moderating social and ethical considerations (Seidler and Bawa, 2009). Social and ethical considerations add the dedication to innovation systems and help to overcome inertia due to potential entitlements of established actors. In DIS social resilience and broad participation in economic development play an outstanding role to gain momentum for the fundamental transformation.

The dematerialization and efficiency increasing aspects of digitalization together with the substitution of oil-based materials by bio-based materials of the knowledge-based bioeconomy offer opportunities to switch to a green growth trajectory. Despite strongly decreasing employment in traditional industries due to a rationalization triggered by automation, robots and artificial intelligence, the overall employment trend is likely to be positive in the long run because of the new sectors emerging in the knowledge-based bioeconomy and in the so-called quaternary sector, which comprises new applications in the digital economy like sharing-economy platforms etc.

To set the emergence of a DIS into motion is by far not a simple task. We are confronted with the management of a *complex adaptive system* (Seidler and Bawa, 2009), which requires the management and coordination of extensive interactions in innovation networks, permanent adaptation due to unavoidable surprises in knowledge development because of the immanent strong uncertainty, non-linearities generating positive feedback effects, which might cause phase transitions responsible for emergent properties of the system and various other amplifying effects. However, the purpose of a DIS exactly is to support a fundamental transformation of the world production and consumption systems, which is nothing else than a phase transition from a present day's point of view. So amplifying effects, gaining momentum and managing transition processes at bifurcation points are the genuine activities to be originated in DIS.

To improve our understanding of designing and governing DIS many questions are not yet answered. Among others:

- Concerning societal systems: How can participative elements (e.g., stakeholder engagement in innovation) for a transition towards sustainability be fostered?
- Concerning economic systems: How can sustainable scientific and technological development under uncertainty be governed and designed, and by whom?
- Concerning cultural systems: How can a cultural evolution towards more sustainable (consumption) habits (e.g., sharing economy) and changes in behavior (e.g., socially responsible consumption) be facilitated?
- Concerning economic theory: What are the crucial societal, economic, and cultural "tipping points" in DIS that shape qualitative transitions in complex systems?
- And concerning the conceptual level: How can coordination problems between societal, economic, and cultural elements of DIS be coordinated?

Contributing to an answer of these questions is on our agenda for future research.

**Competing interests**
The author declares that he has no competing interests.

## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 22 August 2017 Accepted: 11 December 2017
Published online: 28 December 2017

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