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How digital tools make circular economy operational in industrial areas: The example of BE CIRCLE

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Industry is facing growing pressure to reduce greenhouse gas (GHG) emissions and waste by regulation. Circular economy principles can be used to optimize resource flows in industry. However, industry still faces concrete financial, regulatory, technological, and organizational barriers to do so. For the establishment of industrial synergies, ecosystems can be seen as a useful concept to frame and implement circular economy principles. New digital tools can support the implementation of circular economy projects, which use field and publicly available data. In this article, we present "BE CIRCLE" as an example for digital services that help to identify new opportunities to cut GHG emissions by closing resource loops. During the development of BE CIRCLE, three case studies with two industrial parks and one port were conducted. The outcomes and learnings are described. In addition, recommendations for data management will be proposed.

1 Introduction

Industry is facing ever growing pressure to reduce greenhouse gas (GHG) emissions and waste. Circular economy is seen as one valuable way to address these issues. The Ellen MacArthur Foundation (2015) estimates that € 1.8 trillion of net economic benefit by 2030 can be created thanks to circular economy initiatives. Circular economy principles can be used to optimize and drive industrial developments. For instance, they can be implemented in industrial parks and eco-industrial parks (EIPs). Indeed, circular economy initiatives still face concrete financial, regulatory, technological, and organizational barriers. A new generation of digital tools is being developed, which can help to overcome these barriers. Therefore, this article includes the following four contributions.

First, this article starts with highlighting the importance of circular economy for industry. Then, it explains the concept of circular economy and industrial synergies. In this context, ecosystems are presented as a relevant space to implement industrial synergies. Subsequently, challenges and barriers for the implementation of circular economy projects are enlisted.

Second, a new generation of digital tools will be described, which use field and publicly available data. These digital tools can help to overcome the identified barriers for implementing circular economy projects.

Third, BE CIRCLE is shown as an example of the latest generation of digital solutions and three case studies are described including their context, the project and the respective outcome plus learnings.

Fourth, recommendations will be given what should be considered while using data for circular economy projects.

2 Why circular economy matters for industry

The reports "The Limits to Growth" (Meadows et al., 1972) and Rockstrom's article (2009) raised high public awareness about the finite supply of natural resources. This has led to several changes in policy and regulation. As a consequence, industry is facing growing pressure to reduce resource consumption, GHG emissions, waste and other environmental impacts (e.g. European Union Emissions Trade Scheme (EU ETS)). In the same time, local authorities try to develop sustainable areas such as EIPs. EIPs can be defined as a dedicated area for industrial use at a suitable site, which ensures sustainability through the integration of social, economic, and environmental quality aspects into its site planning, management and operations (Lowe, 1997). Today, worldwide about 250 EIPs are currently operating or under development as opposed to fewer than 50 in the year 2000 (World Bank group, 2017).

Concerning the measurement of industry's environmental impact, end-of-pipe solutions were the first measures, which were introduced to control and treat pollutions in production. Subsequently, cleaner production practices have been implemented to prevent or reduce pollutions by optimizing processes, which then require less resources input and output, or substitute toxic through non-toxic materials or use renewables. The latest environmental solutions are more systemic including lifecycle thinking and have the aim to close production loops within an industrial ecology like EIPs (OECD, 2009).

Therefore, industry managers must develop long-term strategies that integrate the triple bottom line (TBL) in their activities and business models, which combines the 3 Ps including People (social layer), Planet (environmental layer) and Profit (economic layer) (Joyce & Paquin, 2016). For this reason, industry managers must develop solutions that are consistent with people's behavior, consider the limited resources of the planet and that are efficiently and economically produced.

2.1 A useful concept to change production modes

In this context, the concept of circular economy has emerged during the last 20 years as a promising response to these challenges (Lieder and Rashid, 2016), while regional and national policies have included circular economy in their political agenda (e.g. European Union Circular Economy Package and China's Circular Economy Promotion Law). In contrast to the predominant linear economy, in which continuous growth is based on an increasing resource extraction and follows the logic of "take, make, and waste", the circular economy is a successful paradigm shift (Geissdoerfer et al., 2017) and an attractive management concept to change production modes in industry (Preston, 2012). It is the "realization of closed loop material flow in the whole economic system" (Geng and Doberstein, 2008) aiming at the decoupling of growth from resources. The route to a sustainable economy leads to a closed-loop system where nothing is allowed to be wasted or discarded into the environment, which reuses, repairs, and remakes in preference to recycling (Bocken et al., 2014). The system must be built on collaboration and sharing, and emphasizes delivery of functionality and experience instead of product ownership.

2.2 How to build ecosystems for circular economy: Industrial synergies

Many companies are located in industrial areas or parks interacting with multiple stakeholders and other companies while exchanging products, resources, and services (Zeng et al., 2017) within what can be called an ecosystem. A business 'ecosystem' can be seen as a structured community of organizations, institutions, and individuals that impact the firm and the firm's customers and suppliers (Moore, 1993; Teece, 2007). The ecosystem of an industrial firm includes competitors, complementors, suppliers, regulatory authorities, standard-setting bodies, the judiciary, and educational and research institutions and it has major impacts on the firm's competitiveness (Teece, 2007). Hence, the ecosystem perspective is a suitable framework to implement circular economy approaches. An ecosystem can be implemented through industrial synergies (IS)[1], in which geographically close industries can develop a competitive advantage by the synergetic exchange of materials, resources, energy, water and by-products (Chertow, 2000). IS are concerned with closing material streams and loops by using wastes from one facility as an alternative input for another facility (Van Berkel et al., 2009).

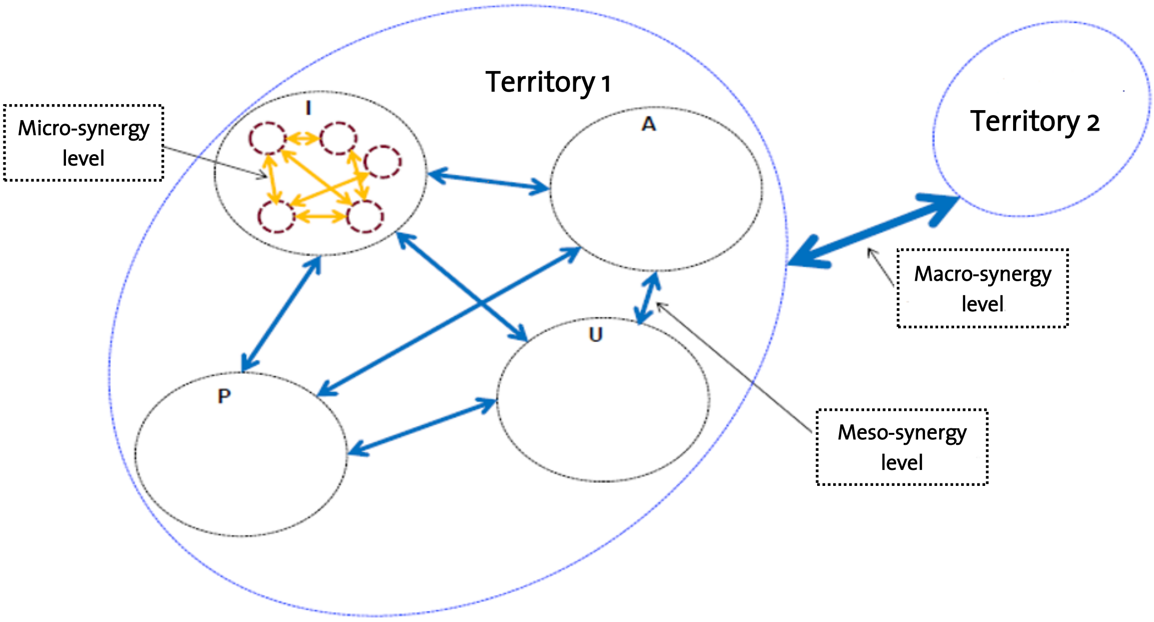
Industrial parks can be considered as an ecosystem consisting of various stakeholders exchanging resources and creating industrial synergies. In an industrial park, circular economy approaches can be implemented at three different levels that correspond to their spatial scope (Mat, 2015). First, the firm's level is the micro-level (e.g. the production plant). Second, the local ecosystem is the meso-level (e.g. industrial park), and third, the regional ecosystem is the macro-level (e.g. region). Spatial proximity and the possible connections define the type of synergies that can be implemented. At the firm's level, micro-synergies are implemented within one production plant. At the industrial park's level, meso-synergies can be implemented through the exchange of resource flows between different firms. At the regional level, other types of synergies can be implemented beyond the local borders of the industrial park. The three different types of synergies are summarized in Figure 1.

According to Boons et al. (2017), several types for the establishment of industrial synergies can be identified and characterized by the initiating actor(s), their motivation and typical outcomes (see Table 1). Local governments and/or industrial stakeholders can elaborate a strategy for the development of an eco-cluster or EIP. In this participatory process, which involves multiple stakeholders, symbiotic linkages between the different stakeholders are identified and developed. This process aims at the (re-)development of areas, brownfields, greenfields, and innovation clusters and is part of a broader strategy for eco-innovative solutions.

2.3 Relevant ecosystem stakeholders for industrial synergies

Ecosystems and IS link different categories of stakeholders that work and influence each other. These categories include private stakehold-

Figure 1 Different levels of synergies (source: Mat, 2015).



[1] Industrial synergies refer to the operationalization of the paradigm of industrial ecology through closed-loops of matter and energy (Dumoulin and Wassemaar, 2014). Industrial synergies are defined as physical exchanges of materials, energy, water, and by-products among diversified clusters of firms (Chertow, 2007). They engage diverse organizations in a network to foster eco-innovation and long-term culture change (Lombardi et al., 2012). In this article, we use industrial synergies as a generic term for flows and material exchanges. Industrial symbiosis and industrial synergies are comparable terms, especially when used by practitioners (e.g. Huber and Corma, 2007).

Table 1 Different types of industrial symbiosis including their initiating actor(s), their motivation and typical outcomes (source: Boons et al., 2017).

Type of industrial symbiosis	Initiating actor(s)	Motivation of the initiating actor(s)	Typical outcomes
Self-organization	Industrial actor	See economic and/or environmental benefits from IS	Agglomeration Hub-and-spoke network Decentralized network
Organizational boundary change	Industrial actor	Eco-efficiency and business strategy	
Facilitation-brokerage	A public or private third-party organization	Establish/increase transparency of market for firms to develop IS	One-off network of symbiotic exchanges
Facilitation – collective learning	A public or private third-party organization	Enable firms to develop tacit knowledge and exchange experiences	
Pilot facilitation and dissemination	A public or private third-party organization	Learn from nonlocal existing IS cases and experiment in a local context	Diffusion of IS concept among clusters
Government planning	Governmental actor(s)	Learn from existing IS cases and implement	
Eco-cluster development	Governmental and/or industrial actor(s)	Innovation, economic development	Redevelopment Brownfield development Greenfield development Innovation cluster

ers and public local authorities. For instance, they are firms, industrial park planners and developers, industrial park operators and management, industrial or business associations, chambers of commerce, regional and local governments, and funding agencies (World Bank Group, 2017).

The different stakeholders of the ecosystem can consider and plan their activities according to three different time horizons: (1) operational planning (short-term reaction to a declared urgent situation), (2) technical planning (middle -term strategy of precaution in response), and (3) strategic planning (long-term ambition in order to provide needed changes) (Mat, 2015).

Each stakeholder has distinct needs according to their respective position in the value chain and function. This depends on the kind of networks and resource flows which they have to manage. At the micro level, industrial managers pursue mainly cost and production control strategies. At the meso level, network and utilities managers need to optimize and develop further their infrastructure while ensuring everyday operations of their network's users. At the macro level, industrial park managers and developers try to attract new industries and find connections and synergies either at the local level or beyond the industrial park's borders.

In general, industrial stakeholders mainly focus on cost savings in terms of reduced material and energy prices, which represent strong incentives to engage in synergy search. Besides, an increasing market demand for green solutions provides an incentive to engage into the development of sustainable solutions - what could lead to a higher market share when offering green solutions (Porter and van der Linde, 1995; Triguero et al., 2013). Finally, industrial stakeholders must consider changes in regulation as the introduction of new standards may require the development of environmentally friendly solutions and to avoid penalties or higher taxes (Triguero et al., 2013).

In contrast to industrial stakeholders, local and regulatory authorities, economic development agencies or associations have a strong interest to (re)develop brownfields and greenfields, industrial areas and parks to increase the attractiveness, competitiveness and employment of their region (Boons et al., 2017). They pursue rather social and economic goals. They promote the sustainable use of land with different scopes (single plot of land vs. larger area like an industrial park) and work within different timeframes (e.g. short term synergy matching vs. long term infrastructure planning). Furthermore, they seek to favor better working and labor conditions, direct and indirect employment creation and support technology and knowledge transfer through investments (World Bank Group, 2017).

Therefore, each stakeholder may need and develop different capabilities. In the context of a circular economy, cooperation and being part of a network becomes increasingly important (Boons et al., 2017). Industrial stakeholders can develop technological and management capabilities, implement collaboration with research institutes, agencies and universities to access external information and knowledge to push the development of technological solutions (Triguero et al., 2013).

2.4 Challenges for relevant ecosystem stakeholders

For the build-up of an ecosystem, stakeholders must take into account the following challenges:

First, delineating the potential playground for circular economy projects and identifying the relevant stakeholders may be difficult. It is sometimes hardly possible to see where producers and emitters of resources are located in order to discuss circular economy approaches in an (industrial) area or region. This is often the case when a stakeholder does not know the respective area very well. Available resource flows must be quantified and visualized to enable discussions with other relevant stakeholders. In particular, industrial park managers and especially the public entities in charge of economic development have a certain interest to build the industrial fabric of an area or region. They must develop long-term strategies to complete their vision and knowledge of the industrial area or region, which they manage. This is also useful for their territorial marketing activities to show the attractiveness of an area or region. For instance, a crucial task for them is the pooling of resources and transport to achieve modal shifts. Concerning the attractiveness of an industrial park, industrial park developers need to deliver high quality services beyond land sales or rent for potential clients. In industrial areas, network operators must be able to identify additional renewable or recovery supply for resources to increase the environmental performance of their offer in order to comply with local regulations and to respond to their clients' needs.

Second, field and publicly available data must be gathered for the visualization of the ecosystem. Bundling information from different databases is a real challenge, which calls for specific competences and tools (e.g. geographical data analysis for industrial ecology issues, or land planning). For instance, designing a supporting system for novel and complementary visualization of data requires competences that are not available at hand (e.g. illustrate and show existing data in another format). Interoperability potential with existing tools is a key demand as existing data and tools are already implemented and used.

Third, circular economy benefits must be translated into tangible results. Industry managers must be able to identify and quantify synergies and define economic and environmental gains. In general, it is difficult to predict, which projects will be successfully implemented. Optimization of resource flows can be limited, and the existing tools and solutions may not cover all aspects of uncertainty and complexity. Consequently, scenarios are needed reflecting the complexity in management decisions to explore various resource management choices and handle multiple commodities (e.g. waters, energies, materials) and technologies at the same time. In addition, industry managers, in-

Table 2 Categories of sets of indicators for sustainable manufacturing (source: OECD, 2009).

Category	Description	Similar indicators or examples
Individual indicators	Measure single aspects individually	Core set of indicators Minimum set of indicators
Key performance Indicators (KPIs)	A limited number of indicators for measuring key aspects that are defined according to organisational goals	
Composite indicies	Synthesis of groups of individual indicators that is expressed by only a few indices	
Material flow analysis (MFA)	A quantitative measure of the flows of material and energy through a production process	Material balance Input-output analysis Material flow accounting Exergy; Material input per service (MIPS); Ecological rucksack
Environmnetal accounting	Calculate environment-related costs and benefits in a similar way to financial accounting system	Environmental management accounting Total cost assessment Cost-benefit analysis Material flow cost accounting
Eco-efficiency indicators	Ratio of environmental impacts to economic value created	Factor
Lifecycle assessment (LCA) indicators	Measure environmental impacts from all stages of production and consumption of a product/service	Ecological footprint Carbon footprint; Water footprint
Sustainability reporting indicators	A range of indicators for corporate non-financial performance to stakeholders	Global Reporting Initiative (GRI) Guidelines Carbon Disclosure Project
Socially responsible investment (SRI) indices	Indices set and used by the financial community to benchmark corporate sustainability performance	Dow Jones Sustainability Indexes FTSE4Good Index

dustrial park developers and local representatives must quantify the progress, which was achieved because of circular economy projects. Therefore, decision makers generally rely on previously defined key performance indicators (KPIs). These KPIs can be then used for their investment decision based on the complementarities, which they identify with the respective ecosystem. Table 2 provides an overview about possible categories of sets of indicators for sustainable manufacturing.

Fourth, circular economy promoters need to communicate results towards policy and decision-makers. The use of reporting tools and support documents allows the effective and efficient presentation of results towards different stakeholders.

2.5 Barriers to the implementation of circular economy

In projects, the implementation of circular economy principles encounter different types of barriers: finance, regulations and norms, technology, legal, organization and behavior (Ammoury, 2017; Bocken et al., 2017, Triguero et al., 2013, World Bank Group, 2017):

Financial barriers: Sustainable investment is often perceived as non-profitable (e.g. insufficient financial returns or long term returns, high implementation costs) and hence, call for financial support that is not always provided by private banks. Industrial synergies are long-term installations and investments. Therefore, it is difficult to guarantee the system's resilience over time with new and changing conditions while predicting the financial implications, if one partner will leave, who previously secured a continuous resource supply.

Regulatory and normative barriers: Required authorization for industrial facilities can be difficult to obtain or may face the "Not in My Backyard" (NIMBY) phenomenon what may prevent the installation of new facilities and production plants. Moreover, lack of traceability or knowledge on the status of waste may prevent reuse of materials in new products or processes. Frequently, waste cannot be transported as a usual commodity and requires authorization to circulate.

Technological barriers: Technology may be a barrier to engage in a circular economy because of high switching costs when developing and deploying new technologies. Besides, closing material and resource loops is not always possible: much of the materials currently consumed are in dissipative uses, or others are commingled with other substances and thus difficult to recycle. The lack of existing technology or cost-efficient solutions, the demand for high quality of material, or energy flows can prevent the reuse of available waste or by-products. In addition, recycling solutions cannot always replace virgin materials. In some industries, recycled resources do not fulfil the material requirements in production (e.g. in high-end applications in industries such as medicine or automotive). In particular, recycled material is not used in high-performance materials because they might affect the constitution and stability of the surfaces of these materials and producers are afraid that they could be sued, if products will not fulfil the indicated product characteristics. Finally, necessary competences for synergy design or implementation may be also not available.

Legal barriers: Legal aspects can make the implementation of synergies difficult such as stakeholders' mutual dependency and competition. For instance, contracts must ensure a constant amount of resource supply, but sometimes waste is not produced at a constant level, or production sites of partners may be relocated.

Organizational and behavioral barriers: At a global level, political will and appropriate policies may miss and discourage the closing of resource and material loops. At the firm's level, missing collaboration and secrecy culture, and organizational complexity may lead to a lack of awareness and information sharing. This prevents trust, cooperation and involvement. Competition and the need to protect confidential data can hinder cooperation. Hence, individual strategies may not match together (long-term involvement vs. opportunistic behaviors). Eventually, some firms do not properly separate and collect waste what also impedes the recycling and reuse of materials. This also prevents the collection of data on existing waste streams. Furthermore, potential consumers are not always aware of available materials and resource flows.

The previous described barriers lead to uncaptured value at the end-of-life stage of a product. The main sources of value uncaptured at the end-of-life stage of a product for recycle, reuse and remanufacture are summarized in Table 3.

3 How a new generation of digital tools and services can support circular economy in industrial areas

Governments release public data opening the way to new opportunities (Blakemore et al., 2006; Jetzek et al., 2012). In doing so, business entities can add value to open data and generate revenue through re-using and disseminating them in a new form (Cerrillo-i-Martínez, 2012; Ubaldi, 2013). With renewed functionalities the use of data provide novel opportunities to make certain tasks easier in various industries, e.g.: data collected from satellite imaged for agriculture (Kamilaris et al., 2017), forecast and urban planning (Kitchin, 2014), and the launch of portals (Mahadevan, 2000). Geographical information systems (GIS) and the modelling of systems are typical functionalities of digital tools, whose quality can be improved by the use of real-time data. Digital tools and services are developed on both field and publicly available data.

In general, tools are used either to trigger circular economy initiatives or help to monitor

Table 3 Main sources of value uncaptured at end-of-life stage of a product (source: Yang et al., 2017).

Sources	Details
Recycle	▪ No or little recycling ▪ Lack of awareness and knowledge of recycling ▪ Valuable materials in discarded products ▪ Low-value disposal of recycled products ▪ No customer demand for recycling ▪ Lack of recycling guidance and methods
Reuse	▪ Idle, usable, re-purchased old products ▪ Insufficient use of usable old products ▪ Usable products discarded by customers ▪ Low-value disposal of usable products and components ▪ Poor customer acceptance of reuse of products ▪ Small market for used products
Remanufacture	▪ No or little remanufacturing ▪ Lack of awareness and knowledge of remanufacturing ▪ Need for low-cost remanufacturing technology ▪ No customer demand for remanufacturing ▪ Low acceptance by customer of remanufacture products ▪ Lack of remanufacturing guidance and methods

industrial synergies at an operational level. Some tools are more developed within one industry while others can embrace more sectors. For data visualization and IS identification, these digital tools and related methods usually rely on and combine data from generic databases, field data and publicly available data including governmental open data.

Different generations of tools were designed and launched as circular economy has developed over years, partly triggered by regulatory changes. They have been adapted to individual demand since the local context of users can differ strongly and especially among different countries with distinct regulation. In general, many of these tools were developed by universities or scholars and have evolved differently. The tools help to structure circular approaches and facilitate collaboration through partner and resource flow identification inlcuding information sharing. They also help to support design and land development processes through identification of suitable locations or land revenue optimization. In addition, they address different perspectives of sustainability ranging from facilitation tools (e.g. workshops), material flow analysis (MFA) to circular economy supporting methodologies developed by universities.

Existing tools and services can be sorted by the kind of circular economy or synergy approach they provide: empirical, deductive, or systematic approach (Harpet and Gully, 2013).

The empirical approach consists in following a trial and error process, but deals with a limited number of material and energy flows depending on circumstances and context. Forum and exchange workshops rely on such empirical approaches. A well-known digital tool, which follows the empirical approach, is NextGenPSD2 Implementation Support Programme (NISP ®). It has been developed in the UK and is diffused in other countries as well. The French environment agency Agency de l'Environnement et de la Maîtrise de l'Énergie (ADEME) has been using it in an extensive way.

The deductive approach helps to identify theoretical or technically feasible synergies based upon major resource or material flows related to one industry. They rely on (industrial) databases and identified flows. Umberto® is an example for tools based on the deductive approach.

The third approach is called systematic, which identifies and analyzes resource and material flows within a given system, from an industrial facility to all entities located in an area.

However, each approach considered individually suffers from specific drawbacks. Field approaches may identify synergies that are not feasible. Exchanges are rather casual than formally contracted. Besides, deductive approaches identify a limited number of flows and thus, synergies may lack reliable data and do not cover all resource and material flows. Hence, this is not very practicable for users. Finally, systematic approaches focus on a small number of flows, as they seek to optimize the lifecycle of materials or address one specific industry. Only few tools combine all three approaches and provide functionalities for interoperability among them.

4 Case studies: BE CIRCLE as an example of new digital tools and services for implementing circular economy

As an example for the new generation of digital tools that combine all three approaches, BE CIRCLE has been developed to lever barriers to circular economy. The service BE CIRCLE was developed during the course of an EU funded project by EIT Climate-KIC. It consists of services based upon a web platform to help industrial users implement circular economy approaches while using field data. In total, the service was tested by three experimenters. Two industrial parks tested BE CIRCLE, which were Espace INSPIRA in France and Industriepark Höchst with Provadis School of International Management and Technology in Germany and one port, which was the Port of Dunkirk in France. Each case study will be explained in detail below including a short description of the context of the project, the project and respective learnings and outcomes.

4.1 Case Study I: Industrial park INSPIRA

Context of the project: The Espace industriel responsable et multimodal INSPIRA (INSPIRA) is the second port site of the Rhone valley, located in the region Auvergne-Rhône-Alpes, 40 minutes south of Lyon. In the early 1970s the current INSPIRA site was mainly an agricultural area along the Rhône canal in the East of France. The industrial port has evolved since as a multi-modal hub thanks to various transport modes accessible on-site (waterway, railway and road). Moreover, spontaneous industrial synergies such as heat or hydrogen exchanges have developed between occupants and the neighboring chemistry platform (INSPIRA, 2019).

In 2009, the public entity Syndicat Mixte INSPIRA (SM INSPIRA) was created to organize, manage and further develop the industrial port. Very quickly after starting operations, SM INSPIRA recognized the opportunity to become one of the leading European eco-industrial parks. Its development strategy has henceforth consistently incorporated sustainability, of which industrial ecology is a key component. Today SM INSPIRA covers 330 ha, with 23 companies onsite of which 70% are members of a recently created association of enterprises on the site, and 160 ha remaining for new industrial manufacturers.

Description of the project: As a young entity with almost half of its land available, SM INSPIRA aims at developing a marketing strategy compliant with its principles of development and based on a circular economy approach.

The objective of the experimentation was to support the development of SM INSPIRA's marketing strategy focusing on two aspects: represent existing and potential synergies with the INSPIRA's industrial ecosystem, and identify the best locations for new plants that will facilitate industrial synergy creation with environmental and economic value.

In order to do so, information about INSPIRA's land management was integrated into the BE CIRCLE platform: utilities networks, telecom network, risk areas and easements. Along with SM INSPIRA, the port manager CNR was involved. Those two stakeholders have strong relationships with the industrial plants located on INSPIRA, hence they could echo their needs. Then the industrial plants were modelled to display the resource flows as inputs and outputs. SM INSPIRA and CNR modelled the industrial synergies already on-going between the facilities.

Subsequently, INSPIRA has been using the tool to promote its development strategy, communicate about its commitment regarding industrial ecology and facilitate decision process for new industrial entities.

Learnings and outcome of the project: In this experiment, BE CIRCLE helped to overcome different barriers. First, thanks to the use of generic data for the resource flows generation, the issue of industrial secrecy was resolved, allowing to triggering discussions about potential industrial symbiosis thanks to collaborative scenarios without having to share any specific data. When the future partners are getting ready to sign a Non-Disclosure Agreement (NDA) and share their own data to pursue feasibility studies, then the field data can be integrated into the BE CIRCLE scenarios. The use of an online platform helped to foster collaboration and participative mind-set among the stakeholders.

4.2 Case study II: Industriepark Höchst

Context of the project: The Industriepark Höchst is located in the state of Hesse in Germany and is operated by Infraserv Höchst. In total, more than 90 companies with around 22,000 employees are located at this industrial park, which has a size of over four square kilometers in the area of Frankfurt. Member companies of the industrial park are national and international research and manufacturing corporations, but also service providers (Infraserv, 2019).

Description of the project: The Industriepark is a very well developed industrial park and limited space is left for new settlements. Therefore, the case study aimed at the identification of new opportunities how to connect the industrial park with its external environment. For instance, on the one side, biogenic resources, which are available in the state of Hesse could be used by companies, which are located within the Industriepark Höchst. On the other side, by-products of companies of the Industriepark Höchst can be used outside of the industrial park (e.g. hydrogen as a by-product from the chlorine-alkali electrolysis for hydrogen refueling stations for fuel cell trains).

In a common case study, Provadis School of International Management and Technology and Infraserv Höchst tested the feasibility of exploiting regional open data to display biogenic resources within the Hessian region, which are available nearby the Industriepark Höchst. In general, biogenic resources have an organic source such as biogas or CO_2.

For the realization, of the case study, research was conducted to identify open data sources for regional biogenic resources supply within the state of Hesse. For the supplement of the case study, Infraserv Höchst provided field data for the perimeter of the industrial park plus buildings and transportation ways within the industrial park. For the beta test of the software, data for a pseudo exemplary resource flow network within the Industriepark Höchst were additionally provided.

The aim of the case study was to assess whether field and publicly available data regarding resource flows can be quickly and easily visualized within a large spatial area like a state and in an industrial park at the same time.

Learnings and outcome of the project: The case study combined different complementary approaches. BE CIRCLE could be tested with field and publicly available data for the visualization of resource flows. The integration of field and publicly available data was mainly automatically possible. However, some data must also be converted into another data format and/or manually integrated.

In this case study, BE CIRCLE served as a support tool, which could facilitate the preselection of spots for potential prospects or to identify new applications for (unused) by-products within or outside of the industrial park. This approach can foster discussions from a wider perspective on circular economy approaches and change the mind-set of different stakeholders towards new ideas on how to connect the industrial park with its external environment.

Indeed, companies are generally still reluctant to share data concerning their production to prevent that competitors might obtain insights into their cost structure or their competitive advantage. In addition, an industrial park operator may not possess plenty data regarding the resource inputs or outputs of its clients. Frequently, the industrial park operator only supplies or disposes some of the clients' resources. Hence, further data on the final and by -products of member companies of the industrial park may not be available, which could be then used to identify synergies. For a quick preselection of suitable locations, it may rather be more important to know which resources are generally available at a certain location or in its close or distant environment and visualize their presence and absence. Subsequently, experts can discuss the technical feasibility of closing resource loops or explore further alternatives.

4.3 Case study III: Port of Dunkirk

Context of the project: Dunkirk is the France's third-ranking port. It handles heavy bulk cargoes for numerous industrial installations. Besides, it is well positioned regarding cross-Channel Ro-Ro traffic to Great Britain. The port's territory covers 7,000 hectares and includes ten towns: Dunkirk, Saint-Pol-sur-Mer, Fort-Mardyck, Grande-Synthe, Mardyck, Loon-Plage, Gravelines, Craywick, Saint-Georges-sur-l'Aa and Bourbourg.

The Port has hosted industrial activities since mid-18th century, starting with the establishment of glasswork, faience pottery and cloth manufacture sites. From the 19th century onward major works were carried out in terms of facilities such as the construction of the railway to link Dunkirk to its hinterland, which allowed an important growth of the industrial activities. Today Dunkirk is the 7th port of the North Europe Range which extends from Le Havre to Hamburg (Dunkirk Port, 2019).

Description of the project: Industrial ecology has underpinned the development strategy of the port for several years and became a key component of its competitiveness. One of the main challenges today is about sustaining the existing synergies and developing new ones while certain facilities leave and others establish over time. To handle this, the port has been working on its territorial marketing strategy in order to identify which industrial sector to prospect that will best complement the local ecosystem in terms of complementary resource flows, bringing locally the resources needed by its neighbors and consuming their products and by-products.

A case study emerged with the departure of an old refinery in the eastern part of the port. The question of how to replace it was raised by Port of Dunkirk and Communauté Urbaine de Dunkerque (CUD), to which BE CIRCLE aimed to answer. The eastern part of the port was modelled on the BE CIRCLE platform using sectorial generic profiles for determining the input and output resource flows.

Based on the resources entering and leaving the industrial ecosystem, the "territorial marketing strategy" functionality was launched. The objective of such a functionality is to scan the BE CIRCLE internal database that encompasses the different industrial sectors with their resource profiles (what is produced, what is consumed) in order to identify the best match in terms of resource complementarity. A list of relevant sectors was delivered to the local players with their score of complementarity. Their relevance was discussed in a collaborative and participative approach. Then four sectors were selected in accordance with the port and local authority's preferences. The four related scenarios of establishment were developed and simulated in the platform integrating the potential symbioses with the neighbor facilities. Then, they were compared to each other in terms of environmental, social and economic performance thanks to seven indicators: the relative level of GHG emissions, the level of water circularity (linked to the volume of water reused locally), the part of renewables in the local energy mix, the number of symbioses created, the economic dynamism of the sector considered, the number of jobs created, and the impact on the surrounding road traffic, in terms of trucks flow density. These scenarios fostered the port's strategy regarding its prospection effort and the corresponding marketing arguments.

Learnings and outcome of the project: The case study showed that it was possible to integrate a whole database of industrial sectors profiles in BE CIRCLE in order to support the industrial park managers into their effort for building a consistent and eco-efficient ecosystem and create the favorable conditions for symbioses formation and growth.

5 What to consider while building your own circular economy case study with digital tools

IT tools require data for the visualization of resource flows and identification of synergies between different stakeholders. The following points below should be taken into account while using different data sources for the creation of a case study.

5.1 Data identification and integration

At the beginning, valuable data for the case study must be identified and integrated into the IT tool. In general, one of the main challenges is the access to appropriate and classified data plus their integration into digital tools. For IT tools, it is generally important that data can be compared to support management decision-making and to improve operational performance. In doing so, data aggregation and standardization is very important to collect and compare data. This will help to find innovative products and solutions. However, the indicators may differ from organization to organization depending on their context (OECD, 2009).

5.2 Data updates

Concerning the use of IT tools, one important aspect is the up-to-datedness of data to build valuable and reliable case studies. In general, a high interoperability with existing tools enables the possibility to integrate further data and additional tools can be used to enrich the case study. In particular, IT tools could be used at industrial parks, which are newly built up on a green field and data could be gathered from the beginning on within one data management system. This could reduce data compatibility and integration problems. In general, the aim should be the creation of intelligent data bases, which are connected and automatically update data in real-time or within a given time interval.

In contrast, if a network has a high degree of (technical) complexity, it might be very difficult to keep all data of the system up to date. Data management will be very time-consuming and thus, may not be practical and economically feasible. In this context, IT tools could primarily focus on the collection of data on a qualitative level. In this case, qualitative data should be used, which can be easily gathered and updated. In doing so, questions should start from open questions to more narrowed ones. For instance, the following questions could be used as selection criteria for the identification of novel opportunities for resource supply and use, or to find a suitable location for the establishment of new applications:

1. Is resource X available at a certain area?
2. If yes, which state of aggregation does it have (solid, liquid, gaseous)?
3. If resource X is available in gaseous state, at which pressure is it available (e.g. 1 bar, 3 bar, 7 bar)?
4. Which other resources are also available?

Finally, the insights and findings of such IT tools must provide more value than the time

Table 4 Checklist for data identification, integration and updates (source: own representation).

Data identification and integration	Data updates
▪ Who decides which data can be used and which cannot be used? ▪ How to identify “clean” and “good” data? ▪ How to use inconsistent data and how to “clean” them? ▪ Can all relevant data be gathered in the right format for data integration? ▪ Which and how can data be converted into the right format for data integration? ▪ Is it possible to connect data bases from different work tools of a plant or whole production plants of an industrial park? ▪ How is consistency in the integration of different databases ensured? ▪ How to characterize different industries, resources/ commodities and their respective relevance for the case study?	▪ How is the up-to-datedness of data ensured? ▪ How can the data or databases be automatically integrated and updated? ▪ In which time intervals can data be updated? ▪ Who gives the permission to the system to automatically integrate and update data (employee or autonomous algorithm)?

invested to search, integrate and keep data up to date, or the fee, which must be paid for a service.

Table 4 provides a practical checklist regarding the data management for the application of digital tools in circular economy case studies.

5.3 Human facilitator

The development of digital services requires new competencies and new jobs emerge. Data managers and coordinators are required to facilitate the design and implementation of digital solutions in circular economy projects. Data managers or coordinators are professionals, who bridge customer relationship and circular economy project management by transforming data into valuable content (Lindmann et al., 2015). These novel roles can feed new businesses, which build upon new commercial services such as business intelligence services or exchange platforms.

6 Conclusion

In this article, barriers and challenges for the implementation of circular economy projects were described. Digital tools can help to overcome these barriers by using internal empirical and publicly available data to identify new possibilities of cooperation through the sharing of information and modelling of scenarios. In general, governments tend to release more and more public data bases. This provides new opportunities for the exploitation of publicly available data. Unknown opportunities could be identified without sharing own field data and having a high degree of internal restrictions at the beginning. For the application of digital tools, new roles are emerging. For instance, the role of a data integrator and coordinator becomes increasingly important, who has competences both in industry understanding and data management. New digital services like BE CIRCLE can help to connect stakeholders, change their mind-set and build ecosystems where firms can cooperate and exchange flows in a suitable way. Finally, the United Nations Sustainable Development Goals (UN SDGs) are especially a driver for industry's transition towards a more sustainable use of resources and provide incentives to engage in circular economy approaches (World Bank Group, 2017).

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During the course of the two-year project, a geo data-based web platform including further services was co-developed.

The platform allows defining scenarios for the identification of opportunities, which close resource loops and lead to positive impacts on competitiveness and environmental excellence of the local stakeholders.

BE CIRCLE gained recognition in 2018, where it was awarded the Jury's favorite Prize during the "Rencontres de l'Economie Circulaire" in Lyon. At international level, BE CIRCLE was nominee at the 2018 EIT Innovators Awards organized by the European Institute of Innovation & Technology (EIT), as a team from the EIT Communities that develops high-impact products and services for a sustainable future.

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