Title: HOW ACHIEVING CIRCULAR ECONOMY IN CITIES THROUGH

RESOURCE FLOW ANALYSIS?

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Abstract:

This communication presents an approach of application of circular economy model in a city based on a successful model of public-private collaboration to promote the change from the current linear model to another circular that encourages water reuse, lengthening the life cycle of products, recycling materials and sharing the assets. Considering, at the same time, the needs of the different territorial actors and their relationship with the environment. The authors developed this approach since 2016 in close collaboration with, on the one hand, local governments and, on the other hand, with water utility in the cities. The basis was several innovation projects to promote a more efficient use of resources in the city. Applying circular economy in a territory has same specificities developed in the next methodology:

1- Identification of territorial actors: city council and other supramunicipal administrations, public service providers (water, waste, cleaning, etc.), green spaces (natural parks, agricultural areas, ...), businesses (industrial associations, PIMES and large companies) and social entities (cooperatives, citizen associations);
2- The inventory of water, energy and raw materials-waste flows
3- The analysis of data of these flows with 4.0 methods for the identification of synergies and opportunities for circularity between the actors;
4- The development of a strategic territorial agenda that includes specific actions, valuation of potential environmental, economic and social benefits, as well as identification of barriers to its implementation (administrative, legal, etc.) together with an evaluation of financing model alternatives, of collaboration, of contracting and possible new associated business models;

5- A plan of measures implementation and definition of the transformation projects and, finally;
6- The monitoring and quantification of the real impact of the implemented measures in the territory.

This methodology was tested and implemented in two municipalities resulting in the identification of more than ten circular opportunities. Some are in the implementation phase as the promotion of the industrial use of reclaimed water, the valorisation of specific industrial waste and the development of a collaborative energy model for the companies of the municipality. Finally, we are able to discuss some key elements that are basic for implementing circular economy in a local scale.

Keywords: *circular cities, material flow, resource efficiency*

JEL codes: Q01, Q28, Q48

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INTRODUCTION

The circular economy (CE) concept is one of most discussed recently concerning the need of changing current economic paradigm and achieving sustainability goals. This include not only economic challenges, uncertainty, increasing population, limited resources, biodiversity loss but also social ones as the inclusion of Artificial Intelligence, robots and the impact on employment. Ideas about the need of growth decoupled from natural resources are seen as an alternative or, in some cases, degrowth seems the solution. However, as we found in Haas et al. (2016), the principles under CE has a long history. From preindustrial period, there are examples of reusing and recycling materials but the recent history of industrialization show ways of life and production systems that are not sustainable. Usually, the CE is based on 3R principles of reducing, reusing, and recycling. Reduction refers to minimizing inputs of primary energy and raw materials that we achieve through improvements in product efficiency. Reuse suggests using products and waste in more than one production stage using the products to maximum capacity. Recycling of used materials or resources susbstitutes consumption of raw materials.

Although, as we will see in the next point, CE is not only referring to recycling, this was the first concept introduced in laws. Germany starts implementing CE in 1996 with the law 'Closed Substance Cycle and Waste Management Act'. Japan adopts "The Basic Law for Establishing a Recycling-Based Society' (Heshmati, 2015). China adopted in 2002 a circular economy strategy for all the country through a number of pilot studies implemented in three levels: individual businesses, eco-industrial parks and eco-cities/municipalities (Kalmikova et al., 2018). In other countries like Sweden or in European Union or in specific regions or cities a large amount of actions are taken including private organisations as Ellen Macarthur Foundation (EMF) or the Institute de l'économie circulaire en France.

Nevertheless, CE can be seen as a sustainable development strategy if we are able to integrate environment, economic and social goals. In case the strategy is designed in a production area or in a territory, measures and actions will be not the same. In this paper, we focus in CE applied as a strategy for regions and cities, presenting two case studies of a methodology for cities. This communication presents an approach of application of circular economy model in a city based on a successful model of public-private

collaboration to promote the change from the current linear model to another circular that encourages water reuse, lengthening the life cycle of products, recycling materials and sharing the assets. Considering, at the same time, the needs of the different territorial actors and their relationship with the environment

The paper is divided in five parts. After the introduction, we present a short review about the basis and the circular economy concept, the next part is devoted to the discussion of the circular cities, the presentation of a methodology for analysing the resource flow is the next point, the application of the methodology and the results are the next and, finally, we elaborate some conclusions.

CIRCULAR ECONOMY CONCEPT: STATE OF THE ART

The concept of the **circular economy** has many variants and a rich set of historical antecedents based on industrial ecology research and ecological and environmental economics. In fact, there are many articles discussing the concept and providing definitions. Okorie et al. (2018) include the most recent reviews of the CE paradigm with a short description of their contribution.

Saavedra et al. (2018) investigate the contribution of IE to CE. In this sense, they argue that the industrial ecology (IE)[1] can help in the transformation of industrial system to a sustainable system. For this reason needs to understand the circulation of materials and energy flows and how industrial ecosystem is working in order to help in the transition of industrial system towards CE. The seminal article of IE from Frosch and Gallopoulos (1989) is usually identified as the begin of industrial ecology using the analogies between industrial ecosystems to biological ecosystems. The tools of IE such Industrial Symbiosis and EcoIndustrial Parks (EIPs) allow the evolution of CE based on Material Flow Analysis (MFA) and Ecodesign and Cleaner Production support strategies. The set of ideas based on a biological analogy in varying degrees and forms has been examined in many guises. These include Commoner's "Four Laws of Ecology" (1971), notions of closing and slowing loops (Stahel and Reday-Mulvey 1981), industrial and socio-

[1] Industrial Ecology aims to understand the circulation of materials and energy flows.

economic metabolism (Ayres 1994; Fischer-Kowalski and Hüttler 1998) and cradle to cradle (McDonough and Braungart 2002).

Ayres and Kneese (1969) provide the economic argument for linking economics and environment based on suboptimal allocation of resources and the presence of externalities. It was important to consider externalities, not only as a market failure, but also as a material balance problem. Ayres in 1989 writes the chapter "Industrial Metabolism" concerning the knowledge and understanding the uses of natural resources and their impacts on the environment, in other words, resource efficiency and recycling as a characteristic of industrial processes. Frosch and Gallopoulos in 1989 linked Industrial Ecology and manufacturing strategies (Moureau et al., 2017).

On ecological and environmental economics, Georgescu-Roegen in 1967 was the first of analysing the relationship between economic activities and environment relying on the second law of thermodynamics, the entropy law. Economic system is using energy (it is dissipated and it is no possible to recycle) and materials (can be recycled but also they use energy). Boulding in 1966 considered the Earth as a closed system, Economic system is not closed and self-sufficient but a subsystem of a much broader one, nature. It is a finite system open to the entrance of energy (solar) but closed to the entrance of materials. In this system, economies use resources (not produces resources) and returns waste. In this case, the economic transformation of these elements has an impact in social welfare and producing waste and residual heat. We do not produce neither oil nor fish, nature does. In this economic system, the relationships between economy and environment are circular. Nevertheless, Pearce and Turner (Pearce&Turner, 1990) introduce and describe a circular economic model based on extensive interdependence between the economy and the environment idea. So, the transition from linear or open-ended economic system (take-make-consume-dispose) towards a circular economy (make-consume-reuse-manufacture-repair) is becoming crucial for the humanity (Figure 1). Linear model is relying on large quantities of "free" resources and energy and mainstream in economics hasn´t incorporated these resources. In fact, the assumption is that resources are free. Circular model respects planetary boundaries through increasing the share of renewable or recyclable resources, reducing the consumption of raw materials and energy and cutting emissions and material losses. (EEA, 2016).

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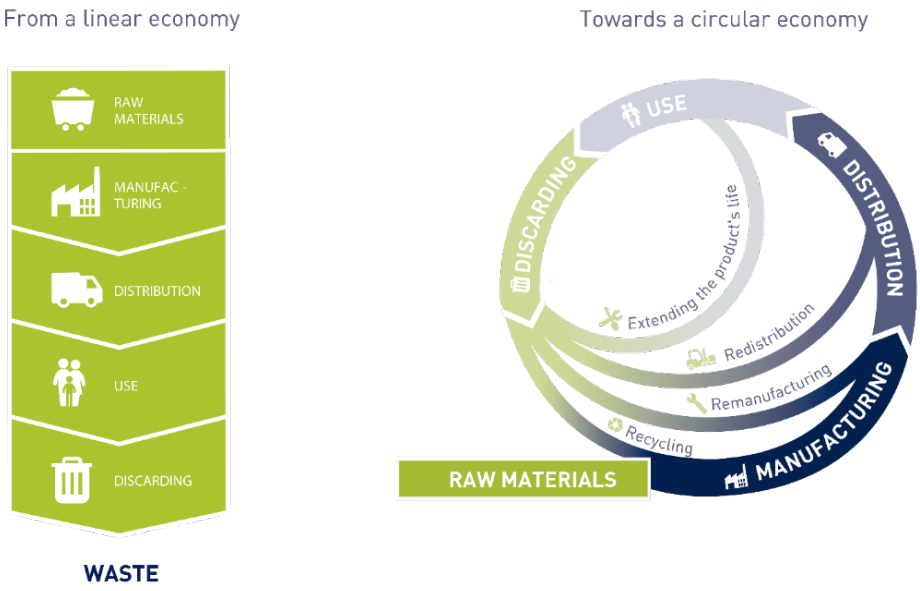


Figure 1. From linear economy towards circular economy model.
Source: Cetaqua own elaboration (2017).

More and more, different reports introduce the concept of urban metabolism, the circular model and the resource-efficient city based on minimisation the use of resources and reducing waste and emissions. (EEA, 2015). At that stage, the core concept is urban sustainability. In 2016, the title of the report was Circular economy in Europe. Developing the knowledge base and the concept was entirely accepted (EEA, 2016). The report says that the concept was relatively new at the European level and has its roots in sustainable development.

Ellen McArthur Foundation (EMF, 2013) has been pioneer on promoting the Circular Economy (CE) concept. According to EMF, a circular economy is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times. At the same time, EMF provides a framework that defines the principles, identifies key components (or actions) and conceptualises how these operate together to achieve a CE (Figure 1).

The EMF defines CE as an economy that provides multiple value-creation mechanisms that are decoupled from the consumption of finite resources. The principles under this

definition are: 1) preservation and enhancement of natural capital by controlling finite stocks and balancing renewable resource flows, 2) optimisation of resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles; and 3) fostering system effectiveness by revealing and designing out negative externalities related to resource use. (Williams, 2019).
The framework also defines six actions that gives the RESOLVE title: Regenerate, Share, Optimise, Loop, Virtualise and Exchange.

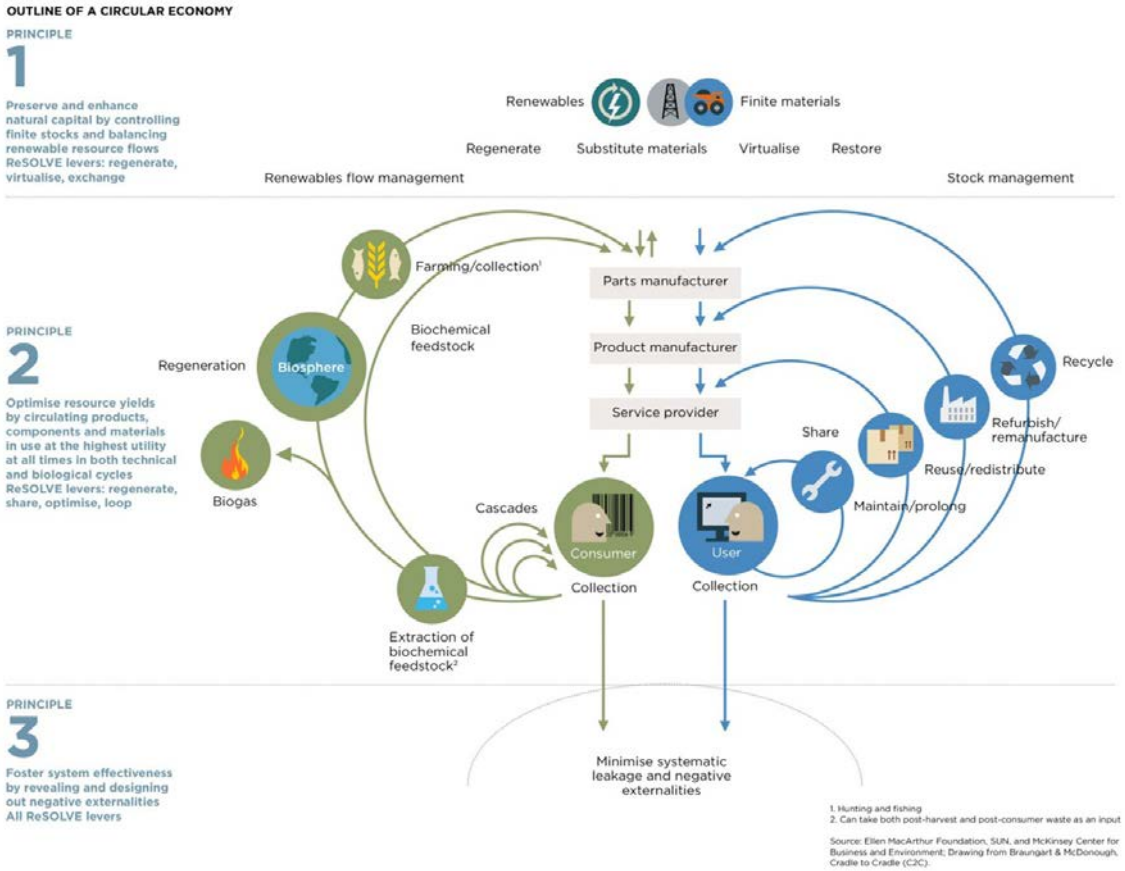


Figure1. RESOLVE- Framework for a circular economy
Source: Ellen MacArthur Foundation, SUN, McKinsey Centre for Business and Environment (2015).

European Union, towards the European Action Plan states that CE "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized" (EU, 2015). As we can see, it places the emphasis on avoiding waste and keeping materials and already extracted resources within the

economy for as long as possible. Nevertheless, this was not exactly in the initial publication (European Commission, 2014a), however, the inclusion of the reduction of our use of raw materials, and thus also the reduction of raw materials at source, in manufacturing products or the realisation of social functions is the final scope.As a conclusion we found two ideas: increasing resource efficiency and closing material cycles. Wautelet (2018) makes an interesting update about the concept of CE, its origins and its evolution including links with the Blue Economy and Biomimicry.

Focusing in a CE, the required change should be in two perspectives: production and consumption as the materials and the flow of energy are in both sides. This implies having a holistic version including a transformation of the socio-technical system of production and consumption, including alternative business models and financing instruments. For example, in production side, symbiosis, eco-design, extended warranty are in mind. In distribution side, the deposit systems, one to one return, leasing, are included. Finally, in consumption side, haring, reuse centres, recycle parks and others are in the focus. A successful transition towards a circular economy requires action at all stages in the value chain: from the extraction and transportation of raw materials, through material and product design, production, distribution and consumption of goods, repair, remanufacturing and reuse schemes, to waste management and recycling. Enabling factors are essential to support the development of the circular economy could include supporting the development, dissemination and uptake of innovative solutions, investing in technology and infrastructure, supporting SMEs and developing the required skills and qualifications.

In case of implementation, Monitoring of CE transition and, at the same time, the impacts of CE should be taken into account and calculated. There are lots of literature about this question as Haupt et al. (2019) summarises. The material-flow based indicators are based on performance rates (e.g. collection rates) but they don´t take into account the value retention and the impact based on life cycle approach for having in mind sustainability. Finally, Circular economy strategy needs the involvement of all different actors in the territory. The participation of different actors in the different parts of the value chain needs to be included.

Implementation of circular economy take in mind life cycle approach and should make the economy and the environment more sustainable. Therefore, the management of the

resources improves due to reduction of extraction and pollution. Moureau et al. (2017) points that CE needs to resolve two important questions: a comprehensive view of biophysical dimensions and the introduction of institutional and social aspects. The need to make a huge political reform not only in recycling but also in changing behaviour is a condition to be successful. In fact, we are engaged in a transition world: energy transition due to Climate Change, economy transition for implementation of CE, technological and social transition too.

MOVING TOWARDS A CIRCULAR ECONOMY: WHAT ABOUT CIRCULAR CITIES?

Transitioning to a more circular economy, where the value of products, materials and resources is maintained for as long as possible and the generation of waste is minimized, is an essential contribution to the EU's long-term efforts to develop a competitive, sustainable, low-carbon and resource-efficient economy. Adopted in December 2015, the **Action Plan for the Circular Economy** is organized into five key areas of action and five priority sectors, with measures covering the whole life cycle of products, from production and consumption to waste management and the market for recovered secondary raw materials...

In order to accelerate the transition towards a Circular Economy, EMF launched in 2015 the Methodology for policymakers "Delivering the circular economy: a toolkit for policymakers". This toolkit aims to support policymakers in designing a strategy to accelerate this process at country level. It offers a systematic methodology to explore and prioritize circular economy opportunities; quantify their impact; identify the barriers preventing these opportunities; map and prioritize the policy interventions to overcome these barriers and to engage relevant stakeholders.

We cannot forget that circular economy has a hard potential for generating positive externalities for environment and economy but also for the quality of spatial development in order to make cities and regions more sustainable and, at the same time, improving the quality of life. In this respect, the CE should be focused in products and in territories too. Territorial economies are designed at different scales but all of them must take

responsibilities for allocating in a rational and efficient way the resources in the territory. Therefore, the way to engage cities and regions on the transition towards CE needs to have evidences on policy actions and measures already promoted including the ways for supporting decision making and data of flows in territories. In fact, urban population represents about 50% of the world's population and they are responsible for 85% of the total GDP, 75% of natural resources consumption, 50% of waste generation, and 60–80% of total greenhouse gas (GHG) emissions (Sukhdev et al., 2016.). WEF (2018) forecast that by 2050, the share of the population living in cities is expected to increase to 70%, increasing the weight of these areas in economic, environment, and social matters.

Cities consume and produce materials, energy, water and land that affects the volume of finite resources. Therefore, there is a need to explore circularity in cities, because they are an ideal location to implement circular changes. Circular cities can be seen as regenerative and self-sustainable systems and the concept takes a lot of sense and derives from the circular economy model applied in the spatial territorial dimension. The circular approach allows including other socio-economic problems in order to improve urban liveability (Williams, 2019) because climate change will increase problems with water availability and quality, energy and food security. Concerning land, the financial crisis has left vacant or half built properties and adding some kind of financialisation of land and housing resulting in the under-utilisation of the resource (Wiliams, 2019) . Cravagnuolo et al.. (2019) analyse circular economy actions in eight European historic port cities self-defined as circular. The conclusions say that there is a lack of measures going beyond "materials and energy" dimensions and open the door to research in assessment of the circular city.

In the case of development of CE in China, the most known pilot case studies are from Dalian, Beijing, Shangai and Tianjin. The four cities are economically developed but have different demographic and industrial features. Assessment of the cities pilot studies are in Heshmati (2015) mentioning that quality of data introduces some doubts about the achievements. In this respect, enough reliable data and information is one of the implementation barriers. There are already some cities making efforts trying to implement a circular agenda and showing interesting actions and measures (Prendeville et al, 2018).

In this context, our approach intends to go beyond the works performed by Circular Economy framework promoting the Circular Economy concept at regional level through **defining, using and validating circular data for designing a strategy** to accelerate the transition towards the circular economy in local cities at Metropolitan Area of Barcelona. This kind of projects have the challenge to manage and analyse all the massive water-energy-waste data collected from the different key actors. For this reason, in this case, the project is also promoting the development of **circular economy** tools to support to consultants or researchers big data intake, visualization and analytics. Upon several use cases experiences we identify the need of a tool as a key factor for scaling up the methodology for **identifying circular economy opportunities** in a city.

METHODOLOGY

The RESOLVE framework in Circular Economy from Ellen MacArthur Foundation is more convenient for businesses but has some problems in case of applying to circular cities (Williams, 2019). In our project, we develop a **holistic methodology for implementing a regional Circular Economy Model** considering an input-output flow analysis (in terms of water, energy and waste) of regional key actors.

The methodology starts identifying the **regional/local actors that play a territorial role in cities**. This analysis has been conducted from an economic, environmental, social and governance perspective in order to map all key actors (public or private) in a region which should be involved to move towards to a circular economy model. These actors include the city council, utilities (water, waste, energy, others), industries and SMEs, citizens, natural areas managers, farmers, other supra-administrations with competences at regional level, among others. A review of a legislative framework in terms of water and waste management, and energy production has been performed.

The project describes step by step how to detect opportunities of circularity from water, energy, waste and resources linking inputs and outputs from each regional key actor, according to legislative framework and will set the basis for its evaluation and prioritisation.

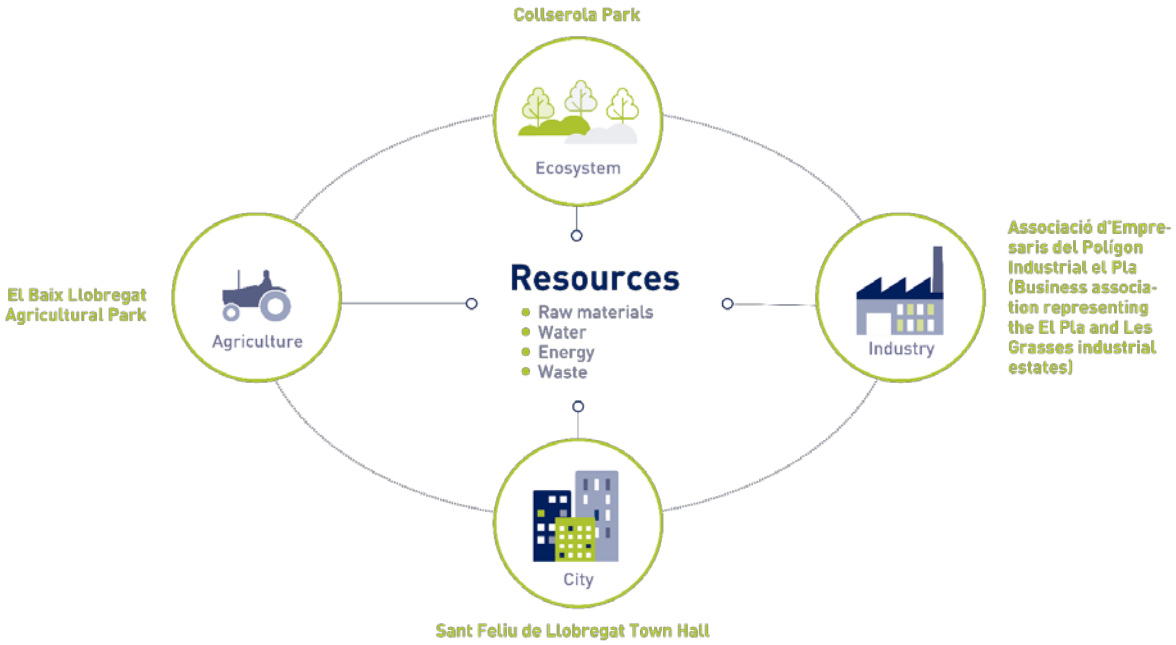


Figure 2. Key actors to promote circular economy in the case studies.
Source: Cetaqua own elaboration (2017).

The methodology give us some answers to the following needs, providing an analysis and recommendations for:

- **Key actors** identification
- **Data** sources and analytics
- Regional and local **policy** and decision **competences**
- How to **foster communication and dialogue** with key actors and stakeholders
- Data **gathering** and management
- Methodology for **synergies detection** (flow analysis)
- Methodology for **sustainability assessment** (which methods to be used)
- **Indicators** to measure feasibility of proposed actions in economic, social and environmental terms.

However, we take into account different assumptions that we discussed in the next lines:

- **Region** is defined such as an area having definable characteristics (physical, biogeographic, human and economic). Region equals to city, municipality or sum of municipalities.

- **Player** is defined such a participant involved somehow at some of the region's activities or processes. In this project, key actors are entities who play an important role in a territory from socio-economic, environmental and legal perspective: primary sector (agriculture, mining, and forestry), secondary sector (industries), tertiary sector (services and commerce), citizens, public entities (city council and other policy makers) or public or private entities providing services (utilities).
- **Resource flows:** inputs (energy, water, raw materials) and outputs (wastewater, waste, emissions) of key actors in a region in order to perform their activities.
- **Opportunities or synergies** key actors' actions that can be performed in a region to close the loop, defining a new circular economy scheme or scenario.

In order to test the methodology, we have two case studies of two cities of Barcelona Metropolitan Area: Sant Feliu de Llobregat (SFLL) and Gavà. Both located in Baix Llobregat area, near to Barcelona city.

In **SFLL case study**, we apply the previous methodology involving eighteen (18) key actors (Figure 3): the City Council, Baix Llobregat Agricultural Park, Collserola Natural Park, local wastewater treatment plant (WWTP)- water utility (Aigües de Barcelona) and 11 industries located in the industrial areas of El Pla and Les Grasses.

In the case of **Gavà,** more than 20 key actors have been involved: the City Council, Garraf Natural Park, and 15 companies from relevant economic sectors: pharmaceutical, metallurgic, construction, gardening and commercial, among others. Aigües de Barcelona has been also involved as local water utility and operator of Wastewater Treatment Plants (WWTPs) with reclaimed water production potential.

After the analysis of the data provided by the key actors and Catalan regional agencies for waste and energy management, up to 10 circular economy opportunities were identified, described and discussed with the City Council and local stakeholders in each of two cities.

Because of the case studies, a set of materials (description, main milestones of a proposed roadmap, actors involved and potential environmental, economic and social impacts) are produced for supporting opportunities further implementation.

Some of these opportunities are **reclaiming water for municipal or industrial purposes, a shared and cooperative industrial waste management system, a shared energy local manager for companies, eco-designed infrastructures, or even proposals to include fiscal incentives at local laws for promoting among regional companies and citizens circular economy best practices.**

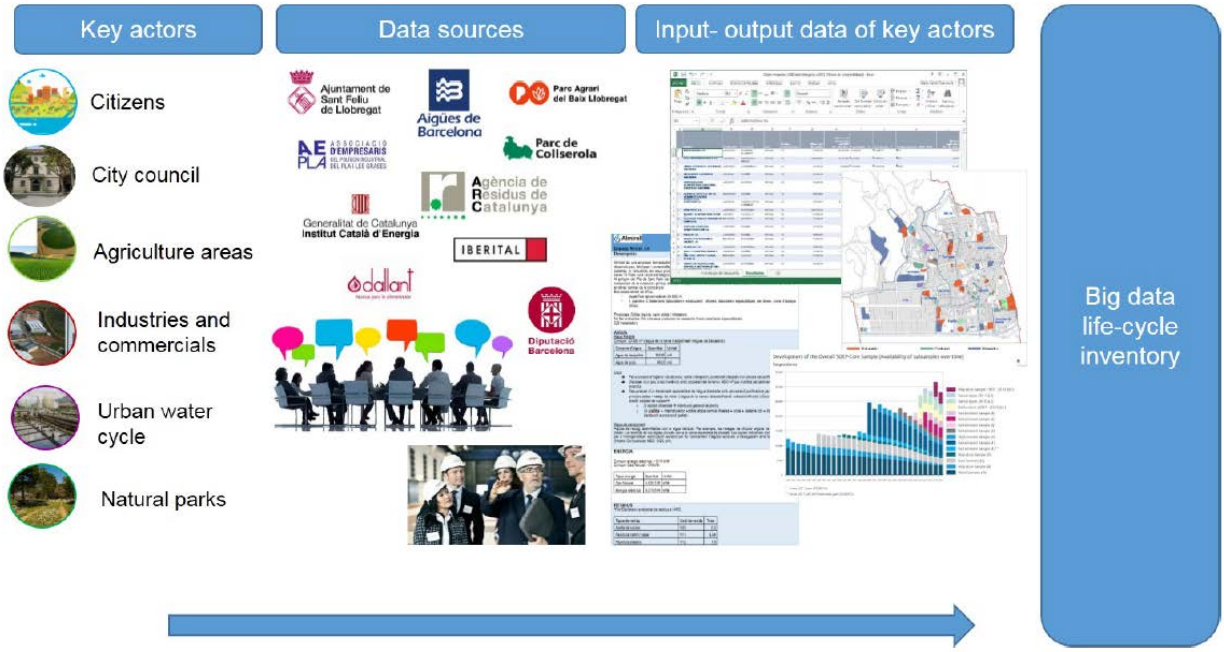
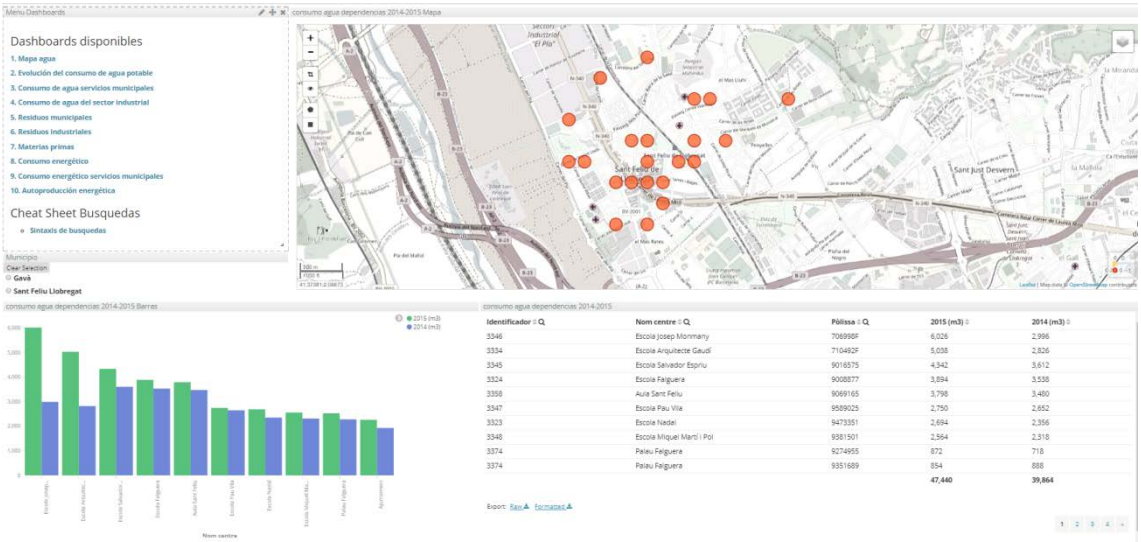


Figure 3. Key actors involved on the project, data sources and flows analysis scheme.
Source: Cetaqua own elaboration (2017)

However, one of the key challenges of these projects have been data gathering, management and analysis. Data on water, energy and waste comes from different actors and sources and in different formats, aggregation level, time horizons and periodicity. The greater the number of actors that can be involved and amount of data gathered and analysed, the greater amount of circular opportunities that can be identified. If all businesses from a municipal area could share their data, rather than 18 business altogether, the amount of opportunities identified would be up-scaled and up-graded. In this regard, the development of tools to aid data gathering, visualisation (Figure 4) and

analysis could greatly up-scale and improve the impact of these projects at the regional level.

Cetaqua has been working in the development of a circular economy tool to assist in the process of data ingestion, visualisation and analysis. Using the Kibana platform (Elasticsearch), part of the amazon web services suite, different visualisation dashboards on water, energy and waste flows have been developed. Additionally, geolocation of information and position of the different actors and key resources of the territory is easy.



Water consumption of municipal installations.

Figure 4. Circular economy tool. Visualisation dashboards.
Source: Cetaqua own elaboration (2017)

This tool benefit to the Circular Economy projects developed in making the identification of circular opportunities more accurate and cost-efficient. We are planning future work for improving this platform and increasing its functionalities.

RESULTS

The main results of these projects are the 10 circular opportunities co-created with the local actors on each of the cities. For each opportunity, we provide a card to the city council with the following information: opportunity name, objectives, description, actors

involved, barriers detected (legal, economic among others) and potential economic, environmental and social impacts of the opportunities if implemented.

In SFLL case study, We estimate in a qualitative way some expected economic, environmental and social impacts of each opportunity. Gavà case study went a step further: **a detailed action plan** for implantation of each opportunity has been defined and **economic, environmental and social impacts have been quantified**:

- **Companies sharing an energy advisor**, it is expected that will reduce the energy consumption up to **10%**, increasing energy efficiency and promoting renewable energy consumption. This means a saving of more than **3000 tons for CO_2** and more than **800.000€** for **industrial** sector and, at least, **1 new position** job is expected to be created.
- **Using reclaimed water for municipal and industrial purposes** will reduce drinking water consumption up to 5%. For companies a 30% cut of its water bill is expected (depending on new reclaimed water tariffs)
- **Sharing an oversized industrial wastewater treatment plant** with other neighbour companies will create new business model for the WWTP owner, increasing its incomes from a new service provided. Besides, industries will reduce its costs related to wastewater management.
- **Creating an Advisory Panel Resource – Waste** for the industrial actors, will give the opportunity to close materials cycles and identifying **raw secondary materials at 0 km.**
- **Reviewing the local laws** from circular economy perspective will give the chance of reducing materials and resources, promoting sustainable materials for the construction sector or promoting assets sharing from several actors

At the end of both projects, results have been disseminated with different activities in order to explain results to the actors involved during the project (City council, companies, other). Public dissemination materials and events were organized targeting other audiences (research community, NGOs, consultancies, etc.) or other local authorities willing to receive a **transfer of the experience and results** (see example Gavà: https://porunaeconomiacircular.es/**).**

These successful experiences on circular economy specific opportunities identified were the result of a public-private collaboration between Aigues de Barcelona (Barcelona water utility) which funds the projects, Cetaqua (Research Center of Aigues de Barcelona) that leads and executes the projects, and city councils, which are the facilitators of the project. City councils help to create the collaborative atmosphere, provide data of its city, they manage to engage to companies and other local authorities and they disseminate the results.

CONCLUSIONS

Due to work carried out on both projects, some considerations have to be taken into account to implement a Circular Economy Model in a city:

- The Legal Framework as understanding applicable legal issues, rights and obligations of public administrations and private companies is essential for implementing a circular model. Administrations will have to work on how reducing barriers for introducing second raw materials into new loops.
- City Councils play a key role to engage actors to participate. Specific computing tools are need to gather and analyse the amount of data collected (big data and analytics techniques needed)
- Circular actions detected have to be assessed from technical, socioeconomic and environmental perspective.
- Actions to disseminate to Circular Economy Model and their benefits for each of the actors are needed in order to involve them during the entire project. This engagement is essential to gather data and validate actions.
- Cities that are committed to the circular management of their resources are innovative cities that are positioned as leaders in the fight against the effects of climate change and the scarcity of resources.
- A circular tool could help to systematize, replicable and up-scale the circular economy model in other cities through the massive data gathering, visualisation and analysis.

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