From the spatialization of LCA to its application in industrial ecology (De l'ACV spatialisée à l'écologie industrielle)

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INTRODUCTION

The concepts of "territory" and "territorialization" lead to strong debates between geographers since the 1960-70s. The political, economic and social dimension of territory is discussed and analyzed according different points of view. To take examples for the most known, Michaël Storper studied the territorialized economic development, in order to understand economic activity depending on territorial resources (Storper 1997), whereas Claude Raffestin talks about the `social space', using the idea of Henri Lefebvre, in order to designate a `production' that which makes a community from an ecosystem that is apportioned to it. Therefore, territory is the result of the production of actors (Raffestin et Butler 2012). This paper doesn't aim to discuss the legitimacy of territory's concept but we aim to use the term in order to make the link between industrial ecology and life cycle assessment.

Industrial ecology and life cycle assessment are both scientific fields which are supported by different applications and methods. Industrial ecology is supposed to understand how to design sustainable industrial systems, whereas life cycle assessment is a method useful to quantify the environmental impacts of a product or service. These issues are important to address according to the territory of

implementation, because the sustainability of industrial system is very dependent on local, urban or regional context. That's why these methods probably need to be improved with a spatial analysis. How to implement the territorial dimension regarding industrial ecology and life cycle assessment? How spatialization of life cycle assessment can improve the industrial ecology application?

The first part will discuss the term of territory regarding industrial ecology and its political and economic application (towards circular economy). The second part will be more focus on life cycle assessment, and how it can be useful for industrial ecology implementation.

INDUSTRIAL ECOLOGY, CIRCULAR ECONOMY AND THE TERRITORY

1. From the territorial dimension in industrial ecology…

The industrial ecology is a scientific field which is structured with the analogy of natural ecosystems (Ehrenfeld, 2004) and supported by the "International Society of Industrial Ecology" (ISIE) and the Journal of Industrial Ecology created in the 1990s. It requires engaging profound changes in the industrial system towards "ecostructuration strategies" (Bourg, 2002). Suren Erkman points out the beginning of this concept during the 1960s, with the pioneers Robert U. Ayres and Preston Cloud in the USA, Jacques Vigneron in France and Peter Baccini in Swisstzerland who worked on the relationship between ecology and economy, and the expression of the oxymoron "industrial ecosystem" (Erkman, 2004).

The industrial ecology field is much known to promote the implementation of operational projects such as the "industrial symbiosis". It aims at developing closing loops of material and energy flows within an industrial area, such as the example of Kalundborg symbiosis which is very often reminded (Christensen, 2006; Jacobsen, 2006). However, industrial ecology can't be limited to the industrial symbiosis and provide research regarding several issues like: Eco-industrial Development, Socio-Economic Metabolism, Sustainable Urban Systems, Organizing Sustainable Consumption and Production, Environmental Extended Input Output, Life Cycle Sustainability Assessment. These topics are all present in the last collective work of the ISIE (Clift et Druckman 2016) and it shows the variety of social, territorial and economic systems which are studied. If we can consider that all of these issues can be studied regarding in their spatial and social dimensions, the concept of territory isn't really discussed. According to our review, the role of territory is seen by the authors, as:

- An area of singular characteristics with industrial boundaries, such as economic activity zones or harbor (Chertow 2007; Mirata et Emtairah 2005; Schiller, Penn, et Basson 2014). In this case, the territory is merely a given area where the park is situated, but it also provides synergy's opportunities because of the geographical proximity of industrial

stakeholders. For some authors, the territory plays a role in the synergies as resources provider or project facilitator (Beaurain et Brullot 2011; Boons, Spekkink, et Mouzakitis 2011).

- An administrative area within it is possible to study society's metabolisms. Therefore, the territory is correlated to spatial planning. According to the geographical level, it concerns urban, regional or national plans which aim at optimizing the circulation of material and energy flows (Billen, Toussaint, et Peeters 1983; Fischer-Kowalski et Haberl 2007; Kennedy et Hoornweg 2012; Ferrao et Fernández 2013).
- The localization of environmental impacts. These works are focused on life cycle assessment and consumption-based accounting. Hence, the emissions and wastes arose on territory (Life Cycle Sustainability Assessment approach, see for example (Tom Wiedman in Clift et Druckman 2016) and it comes from an area of resource's consumption (Druckman et Jackson 2009).

In France, a new scientific field emerges towards social and spatial analysis of industrial ecology, named "territorial ecology". This concept is defined by Sabine Barles as: "*it is an industrial ecology that is considered in a spatial context and that takes into account the stakeholders and, more generally, the agents involved in material flows, questions their management methods and considers the economic and social consequences of these flows*" (Barles 2010). This definition leads to the organization of an interdisciplinary field of research (N. Buclet 2011; Junqua et Brullot 2015), within social sciences and land planning have a strong role. According to us, the territorial ecology corresponds to (Bahers 2014):

- A territorialized approach of flow circulations and stakeholder's system,
- An implementation of this "resource-waste" ecology in the regional and urban plans.

This new field is very close to the social ecology of the Institute of Social Ecology in Vienna (Haberl et al. 2016). However, it differs in that social ecology is mainly focused on national territory (Austria, Germany, India, China) instead of regional or urban areas as suggested in the territorial ecology.

2. … to the territorialization of circular economy

The new program of circular economy, which has a great success these days, is supposed to fulfill a renewed vision of resources and waste management. According to the French environmental agency (ADEME), industrial symbiosis, products ecodesign, sustainable consumption and the 4R-V (Reduction at source, Reuse of a product, Recovery, Recycling and Valorization of residual material) are the pillars of this political and economic program.

The territorial dimension in the French implementation of circular economy is just mentioned because it requires facilitating *"the reinforcement of cooperation between economic actors at the relevant scale taking into account the principle of*

proximity"[1], as laid down in the first regulatory definition in 2014 within the law of "Energetic Transition"[i]. We can see towards this definition, that there is no indication on which spatial scale, the circular economy strategies are supposed to be implemented. According to the European Union, the territorial approach disappears completely, since the first target is to promote the efficiency of resource's use in order to maximize the economic growth (EC, 2014; 2015)[2][3].

Therefore, few authors use the territorial approach to interrogate the political program of circular economy. Gregson et al. (2015) use the variable of spatial distance to criticize these initiatives which are unable to reuse all the waste at a local scale. The emerging circular economy, according to them, "*entails challenges borne of a conjuncture of politically created markets, material properties and morally defined material circuits*" (Gregson, 2015). The political action of circular economy depends on the issue's appropriation of local actors. This perspective is also studied by researchers, who talks about "generative spaces" for the development of circular economy from citizen engagement (Hobson, 2015). Ghisellini et al. (Ghisellini, Cialani, et Ulgiati 2016) considers that the perspectives of circular economy should be different according to the socio-technical levels (providing information to policy makers at the macro level, development of industrial symbiosis at the meso level, and selling of a service (instead of a product) or its refurbishment and remanufacturing at the micro level). Nevertheless, the spatial issue is only mentioned at the meso level, regarding the Eco-industrial parks. The industrial symbiosis seems thus to reveal the territorial dimension of circular economy. It requires a comprehensive knowledge of local context in order to be implemented, especially regarding local actors interests.

THE LIFE CYCLE ASSESSMENT OF INDUSTRIAL SYMBIOSIS: HOW SPATIALIZATION OF LCA CAN IMPROVE THE QUANTIFICATION OF THE ENVIRONMENTAL BENEFITS OF AN INDUSTRIAL ECOLOGY APPLICATION

3. Industrial symbiosis as spatialized systems

We have seen industrial symbiosis as the most famous example of industrial ecology approach, forming a whole system by setting up synergies between economic agents. The most known type of synergies is the recycling of a waste or a byproduct of one enterprise into a material for an another one. However, literature shows other types of synergies: they can be organizational, relational or strategical (Massard, 2011).

1 Traduced by ourselves

2 European Commission (2014). *The Circular Economy: connecting, creating and conserving value*, Disponible sur < http://ec.europa.eu/environment/circular-economy/>

3 European Commission (2015). *Closing the loop - An EU action plan for the Circular Economy*, Disponible sur < https://ec.europa.eu/priorities/jobs-growth-and-investment/towards-circular-economy_en>

Another aspect of those synergies is the agreement to realize the material exchange and to assure them from the economical fluctuation of raw materials exchange rates. Moreover than relationship based on byproduct recycling, an industrial symbiosis can be defined through the agreement between enterprises which would be otherwise all alone (Jensen, 2012). Setting up of agreements can be facilitated by spatial proximity of the agents allowing a mutual trust (Jensen, 2012; Chertow, 2000). This spatial proximity leads enterprises to share their technical knowledge, best practices and investigations through mutualism, vital for the right working of the symbiosis (Christiansen, 1994 in Ehrenfeld, 1997). Nevertheless, an industrial symbiosis is a spatialized system, in terms of materials and immaterials exchanges, leading agents to a social proximity, depending of their motivations, aims but also to face up environmental and territorial constraints (Chertow, 2000). However, according to several authors (Van Berkel, 2009; Sokka, 2011), industrial symbioses legitimacy is based on the hypothesis that their synergistic exchanges are greener, demonstrated qualitatively but not quantitatively. We can ask ourselves about the quantification of the environmental benefits of industrial symbioses, to valid this hypothesis, often seen on industrial symbioses studies. How environmental evaluation tools can quantify the environmental benefits of industrial symbiosis, which is a spatialized system as we saw? We focus on this study on Life Cycle Assessment (LCA), a sturdy tool to assess environmental assessment of complex systems such as industrial symbiosis.

4. Life Cycle Assessment as a tool to quantify the environmental benefits of an industrial symbiosis

LCA is a normalized method to quantify the potential environmental issues and environmental impacts through the whole life cycle of a product (ISO14044, 2006). Life cycle assessment is an iterative method composed by four phases: the goal and scope definition, the life cycle inventory, the impact quantification and the interpretation of the results of each phase (ISO14040, 2006). Several research work were done to improve the LCA methodology last two decades but very few were applied to industrial symbiosis, showing methodological issues specific to industrial symbiosis (Mattila, 2012). The first one is the quantification of the environmental benefits, by the comparison with a reference system, a reference scenario built to satisfy the same functional unit than the symbiotic scenario (ISO14044, 2006; Martin et al., 2015). The functional unit is an essential point to realize the LCA of industrial symbioses when the aim of the study is to quantify their environmental benefits. Nevertheless, the specific recycling of material flows occurring in industrial symbioses makes the realization of this reference scenario sensitive to methodological assumptions of the author.

The most used reference scenario in the literature is the one based on the studied industrial symbiosis without synergies between the enterprises of the system (van Berkel, 2010; Martin, 2015). To build a scenario without synergies, the author of the LCA should ask which raw material consider instead of the non-recycled byproduct and how this non-recycled byproduct should be managed for every single synergy of

the system. This can be realized with system expansion, considering more raw materials production and more byproducts to manage than the symbiotic scenario. However, this method has weakness from the necessity of using several assumptions (Mattila, 2012). The selection of the suitable reference scenario reduces the overestimation of environmental benefits of the industrial symbiosis (Mattila, 2012).

To consider this sensitivity, different assumptions can be tested by producing several reference scenarios, allowing the realization of a sensitivity analysis (Martin et al., 2015). The sensitivity on reference scenario produces a variability of reference scenarios usable and so a variability of the environmental impacts of those reference scenarios. When making the comparison with the symbiotic scenario, the variability of the environmental impacts of the reference scenarios causes a variability of the environmental benefits of the industrial symbiosis studied. There is a need to quantify this variability to know if the industrial symbiosis leads to environmental benefits and to quantify them.

5. A territorial approach to consider industrial symbioses specificities and quantify its environmental benefits

To face up the reference scenario's variability without realize too much reference scenarios, the realization of a reasonably worst case reference scenario and a reasonably best case reference scenario can be done to quantify the widest variability of those reference scenarios (ILCD, 2010), and so on, to mark out the environmental impact of the industrial symbiosis between those two scenarios. We can assume that all the reference scenarios realizable have an environmental impact included between those two extrema.

Moreover, the environmental impact of the industrial symbiosis can be compared to those of the best case and the worst case.

- If the industrial symbiosis has less environmental impact than the reasonably best case reference scenario, there is a strict environmental benefit of the industrial symbiosis, whatever the reference scenario chosen.

- If the industrial symbiosis has more environmental impact than the reasonably worst case reference scenario, there is a strict environmental detriment of the industrial symbiosis, whatever the reference scenario chosen.

- Between those two extrema, there is a relative environmental benefits, depending of the reference scenario chosen.

The results of our literature review show two different cases with two different approaches to realize the worst case reference scenario:

- If there is currently an industrial symbiosis on the territory, the worst case reference scenario is the studied industrial symbiosis is realized considering the enterprises of the industrial symbiosis without recycling linkages (Sokka et al. 2011;

Eckelman et Chertow 2013; Dong et al. 2014; Martin 2015; Daddi, Nucci, et Iraldo 2017).

- If the industrial symbiosis studied is prospective, the worst case reference scenario is built with average technologies satisfying the same functional unit than the symbiosis (Liu et al. 2011; Blengini et al. 2012; Ammenberg et al. 2015; Mohammed et al. 2016) . This second option can be done realizing an overview of the technical solutions used in the territory, to consider local technologies satisfying the functional unit chosen.

The realization of the reasonably best case scenario needs to show an improvement from the reasonably worst case. The consideration of processes using marginal technologies (e.g. renewable energy instead of fossil energy), and best available technologies to improve the current ones can lead to a best case to substitute worst cases processes, according to our research. Indeed, the implementation of new industrial processes, spatialized like industrial symbiosis, is realized considering economical, social and political motivations (Chertow, 2000). Technical improvements assessed should consider local political priorities, regulation (e.g. waste regulation), and be limited by the availability of raw materials, land availability for the facilities, local competencies to develop and to operate those new technologies but also the social acceptation of the neighborhood.

The interviews of local agents regarding issues and constraints about the different best case reference scenarios assessed lead to the definition of the reasonable best case reference scenarios. Therefore, a strong lever is the satisfaction of most of the local agents considering their own strategical aims and technical improvement needs. This resulting reference scenario has a reasonable probability to be implemented on the territory in the hypothesis that the industrial symbiosis is not developed. The key agents for this evaluation are the local politicians, local experts knowing the environmental issues of the territory, institutions in charge of the waste management and local inhabitants.

CONCLUSION

In conclusion, it appears that a territorial approach is required to assess the environmental benefits of industrial symbiosis. There are a lot of perspectives to improve the LCA methodology with spatial, social and political dimensions, according to the territoriality of industrial symbiosis.

Therefore, urban and territorial metabolism is a powerful concept which could be interesting to mobilize. It provides keys to understand the socio-ecological dynamics (Bahers 2014, Buclet 2015;) towards a better knowledge of the space of resources and actor’s system. Territorial metabolism gives also opportunities to examine the metabolic links between territories, their environments and their supply and disposal territories as a mean to transition towards a circular economy. The analysis of the

inter-territorial relationships from a metabolic functioning point of view constitutes a privileged entrance to reach this perspective.

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