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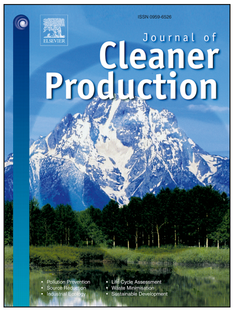

Exploring the performances of urban local symbiosis strategy in Algiers, between a potential of energy use optimization and CO_2 emissions mitigation

Mazia Chaker, Ewa Berezowska-Azzag, Daniela Perrotti

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Mazia Chaker [a, b], Ewa Berezowska-Azzag [a], Daniela Perrotti [c]

[a] *EPAU, École Polytechnique d'Architecture et d'Urbanisme, Laboratoire VUDD Ville, Urbanisme et Développement Durable, Route de Beaulieu, El-Harrach, 16200 Algiers, Algeria, E-mail : chaker.mazia@univ-ghardaia.dz;* em.azzag@epau-alger.edu.dz

[b] *Université de Ghardaïa, route de l'aéroport, BP 455, Ghardaïa, Algeria*

[c] *Université Catholique de Louvain, 1348 Louvain-la-Neuve, Belgium; E-Mail: daniela.perrotti@uclouvain.be*

Corresponding author :

Mazia Chaker , E-mail : chaker.mazia@univ-ghardaia.dz, Tel +213 696 56 70 70

Abstract

Algeria's interest in the global warming issue and its commitment to reduce its GHG emissions by 2030 requires research for operational solutions to support this effort. That entails establishing new urban planning tools, especially at the local urban scale. At the root of harmful Climate Change, cities must exploit their full potential to set up mitigation strategies.

The interest of Industrial Symbioses in optimizing the industrial metabolism led us to explore such a potential for the operational urban planning needs focused on reducing CO_2 emissions. This article aims to study a Low Carbon Urban Symbiosis (LC-UrS) performance at Algiers local scale. Based on a systemic approach, the study defines, firstly, the concerned urban system. Secondly, it explores its perimeter's symbiotic potential to build a database allowing develop the possible symbiotic scenarios and quantify their performance in energy optimization and CO_2 emissions reduction. The gains are then estimated for each scenario. An urban design strategy for the considered optimal scenario is proposed under an action plan for LC-UrS.

The results bring interesting answers for energy optimization and CO_2 emissions reduction, with estimated rates of 30.5% and 13.27% per year, in Algerian's capital city case. This optimizing potential will be even more significant for other cities in the world, particularly with the increase in urban waste. However, implementing such a strategy would require background conditions.

Keywords:

CO_2 Emissions Reduction; Local Urban Planning; Symbiotic Urban System; Low Carbon Urban Symbiosis; Circular Urban Metabolism; Waste- Energy metabolic flows.

Abbreviations list

11066 Words

CC	Climate Change		
EH-OS	El Harrach-Oued Smar	PDAU	Master Plan for urban planning and urban design
HSW	Household and Similar Waste	SNAT	National Territory Planning Scheme
IE	Industrial Ecology	TLC	Technical Landfill Center
IS	Industrial Symbiosis	UM	Urban Metabolism
LC-UrS	Low Carbon Urban Symbiosis	UrS	Urban Symbiosis

1. Introduction

Since the 2000s, global warming speeding up worries the international community. With the increase in global average temperature and the accumulation of Greenhouse gases GHG in the air, the Climate Change (CC) impact turns out to be increasingly irreversible on our environment, our economies, and our security. That requires a coordinated action to meet the challenges of socioeconomic, environmental, and territorial resilience. Algeria is not safe at CC. It is even among the most vulnerable countries to climate disturbance effects. To contribute to the worldwide effort, Algeria has committed to reducing its GHG emissions by 7% by 2030, compared to the current state (INDC, 2015). Realizing such national commitment requires the new tools enabling its implementation at the local scale. As cities are at the core of CC, they are the main contributors and the most vulnerable subjects. Simultaneously, they yet give all potentialities for implementing mitigation strategies.

The main challenge is to reduce CO_2 emissions, the major gas for 76 % of total GHG emissions from fossil fuel combustion (IPCC, 2014). For Algerian cities, CO_2 emissions from fossil resources make up 99.91% of the energy for urban activities, mainly for Housing (36%), transport (41%), and industrial activities (16%) (APRUE, 2017). Their reduction should occur with six sectors' contributions: energy, industry, transport, agriculture and forests, construction, and the environment (INDC, 2015; Berezowska-Azzag et al., 2016). For the first two sectors, the literature review shows that research has often focused on Industrial symbiosis (IS) strategy performances. Though, Urban Symbiosis (UrS), an extended concept of IS, covers possibilities for looping metabolic flows within the broadest framework of a city. However, UrS has not yet proven itself in operational applications (Lorrain, Halpern, and Chevauché, 2018). Unlike IS, which searches to share the flows between industrial compatible processes, UrS searches to reuse both urban and industrial waste (from housing, industrial activities, urban public amenities, and green spaces), as a secondary raw material or energy sources for various urban activities: industrial, agricultural, residential, transport (Erkman, 2004; Van Berkel et al., 2009a; Vernay, 2013; Lufkin et al., 2016; Mulder, 2016), through integrated waste management. Such a strategy of functional diversity has the potential for optimizing energy use and reducing consequent emissions. It could also create a complementary relationship between various urban activities *"by taking advantage of proximity"* (Chertow, 2000). In other words, UrS has not just the potential to redefine urban activities programming and organizing on a local territory. It could likewise add to change urban planning and urban design methods' in the future, with the aim of carbon emissions mitigation.

So, it seems significant to test the performances of a Low Carbon Urban Symbiosis (LC-UrS) in a particular case. The Algerian context appears interesting insofar as, its urban planning tools are looking for a radical overhaul since 2011 (MHUV, 2011) apparently without succeeding, nor incorporating climate issue. This study explores the symbiotic potential at the local scale in Algiers metropolis. We choose the case of El Harrach-Oued Smar (EH-OS), an inter-municipal territory, with a substantial urban and productive potential, including industrial activities, transport infrastructure, and major urban amenities. This local territory undergoes high metabolic flow circulation, high demand for energy, and under pressure on natural resources and the environment (Chaker, 2015). In this context, two questions interest us in particular: *(i) Does the concerned case contain sufficient potential for integrating an UrS strategy, able to optimize local energy use, and thus, mitigate* CO_2

emissions? (ii) If the results would prove encouraging, what would be the conditions for its integration into local urban planning tools?

These questions generate two logical ways for analysis. On the one hand, a systemic approach helps us define the urban study system in its global environment: its boundaries, spatial-functional organization, and purpose. On the other hand, it is to study the mechanisms of its evolution toward the intended UrS and the operational actions it implies, to meet the urban planning and urban design needs. The proposed methodological development combines the theoretical concepts drawn from literature and the operational lessons obtained from the case study. It takes shape with a theoretical model that could be tested and discussed in similar situations (Desthieux, 2005; Thietart et al., 2014) **[Figure1].** Firstly, the article presents the theoretical framework of the UrS concept and outlines its interest in implementing sustainable development policy in Algeria, to describe the global context. Then, it identifies the studied urban system and presents its local context. The methodological section presents the database and describes the methods for modeling a LC-UrS and quantifying the potential of energy optimization and CO_2 emissions reduction for the different symbiotic scenarios. The results, discussed in the following sections, enable identifying the optimal scenario and outline the conditions and constraints of its implementation. Finally, a conclusion prompts observations that answer the underlying inquiries and places them in the larger context.

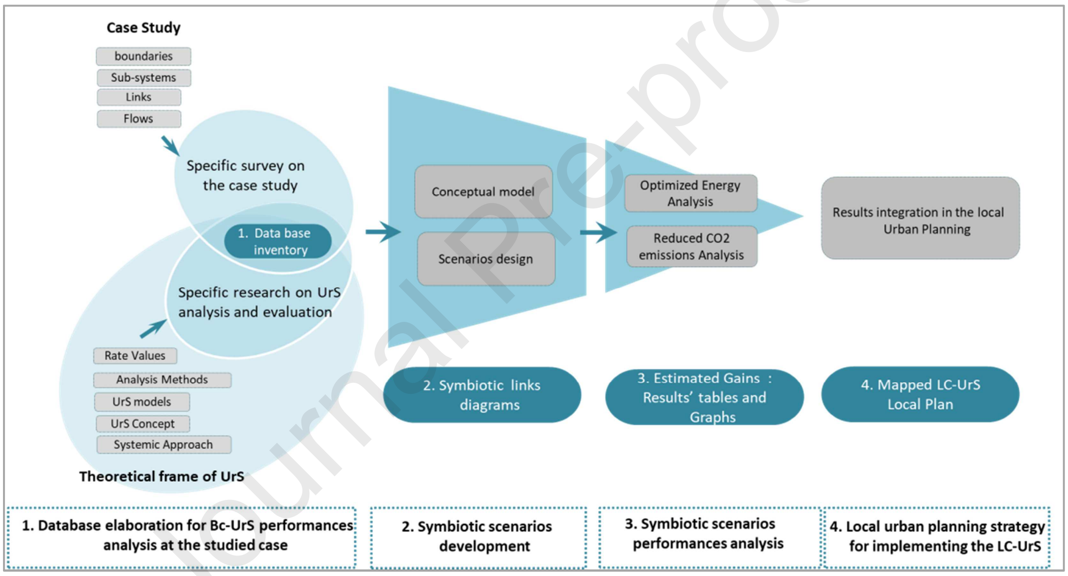


Figure 1: Methodological approach, steps and results

2. Background

2.1. The concept of UrS as an extended concept of IS, literature review

Considered a *practical strategy* to develop a sustainable city (Van Berkel, Fujita, Hashimoto & Geng, 2009b; Ohnishi, H. Dong, Geng, Fujii & Fujita, 2017), UrS was developed, in origin, in the field of Industrial Ecology *(IE)*, as an extended concept of *IS* (Van Berkel et al., 2009b; H. Dong et al., 2014; L. Dong et al., 2016; Ohnishi et al., 2017).

IS was qualified as a relationship that describes the local exchange of resources between different companies (Chertow, 2000, 2007; Lifset & Graedel, 2002; Chertow and Lombardi, 2005; Jacobsen, 2006; Hashimoto et al., 2010; L. Dong et al., 2016). The most cited definition in literature is given by Chertow (2000) [1], who explains the process as *"Industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchanges of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity."* (Chertow, 2000, 2007; Kurup, 2005; Jacobsen, 2006; Van Berkel et al., 2009a; H. Dong et al., 2014; Ohnishi et al.,2017). Thus, *IS* has been categorized as a concept of collective resource optimizatio**n** (Jacobsen, 2006), principally concerned with cyclical flows through networks of businesses (Chertow & Lombardi, 2005). With the development of *IE*, *IS* becomes a sub-field of *IE* (Chertow & Park, 2016). It was diffused throughout significant parts of the world as a practice able to reduce the ecological impact of industrial processes (Boons, Chertow, Park, Spekkink, and Shi, 2017) and ensure ecologically sustainable industrial activity (Chertow & Lombardi, 2005; Berkel et al., 2009a). Since then, the concept of *IS* has evolved considerably, as much theoretically by the significant research effort in the scientific community, as well as in practice (Boons et al., 2016; Chertow & Park, 2016). Several countries have committed to conducting *IS* practice, as examples: the United Kingdom, South Korea, China, North America (Massard et al., 2014; L. Dong et al., 2016). But it was in Japan, with the Japanese Eco-city program launched in 1997, that the concept of *Urban Symbiosis UrS* emerged.

This program has expanded the *IS* initiatives' scope, limited to specific sites, to promote industrial-urban interactions on a larger scale, that of "the city" (Van Berkel et al., 2009b; Geng, Tsuyoshi & Chen, 2010). Thus, the concept of *UrS* was defined by Van Berkel and al. (2009b) as *"the use of by-products (waste) from cities (or urban areas) as alternative raw materials or sources of energy in industrial activities"* (Van Berkel et al., 2009b; Geng et al., 2010; Chen, Fujita, Ohnishi, Fujii & Geng, 2012; H. Dong et al., 2014; L. Dong et al., 2016; Ohnishi et al., 2017). Likewise, the concept of UrS was introduced in the Netherlands as an innovation to create circular urban systems and a more efficient metabolism of cities (Vernay, 2013; Vernay & Mulder, 2016). It was defined as a strategy for optimizing the urban metabolic system by using the proximity of various infrastructures for symbiotic effects, thereby reducing resource consumption and emissions (Mulder, 2016; Mulder, 2017). This approach refers to initiatives aimed at closing material and energy flows within a given urban area (Vernay et Mulder, 2016). It focuses on urban infrastructures in implementing UrS, considering the city as an infrastructural node and an important innovation scale (Mulder, 2016; Mulder, 2017). In Switzerland, Ray (2013) proposes the concept of the "*symbiotic city" to the urban planning field* by transposing the *IE* principles. His approach emphasizes the economic and socio-cultural benefits of a *Cyclical Urban Metabolism*. Ray (2013) defines the symbiotic city as an optimization strategy that seeks to promote a *"syntropic"* urban system, i.e., an ecosystem that allows the encouragement of the economic and socio-cultural development of cities and urban areas, but whose almost cyclical metabolism makes the best use of imported resources and minimizes waste rejection (Rey, 2013; Lufkin, Erkman, & Rey, 2016). Similarly, the concept of *"Symbiotic neighborhood"* was proposed to develop new planning principles and new energy strategies on a smaller spatial scale. This concept helps examine the aspects of urban and architectural development, local autonomy in terms of energy and resources at the neighborhood scale, by integrating issues related to buildings, infrastructure, mobility, goods, and services (Lufkin et al., 2016).

In short, the two concepts *IS/UrS* are a metaphor that takes up the idea *of* food chains *"symbiosis"* in natural ecosystems, where the consumption of energy and materials is optimized, and the waste of one serves as a resource for another (Frosh and Galopolus, 1998; Chertow, 2000; Erkman, 2004; SOFIES, 2011). An industrial/urban ecosystem is, therefore, the space in which an IS/UrS can occur by introducing compelling ties back to natural systems (Chertow & Park, 2016), where geographic proximity, functional diversity, looping flows, and network exchanges are the main implementing principals. Nevertheless, some differences between IS and UrS emerge from the literature review on three key issues : (i) the scale of the system, given that geographic proximity is a well-recognized element for implementing UrS/IS (Chertow & Park, 2016), the local urban scale is a one that is both large enough to offer possibilities for material exchange between actors and small enough, to allow communication and collaboration (Sterr and Ott, 2004; Chertow & Park, 2016); (ii) the objective and scope of the symbiosis, IS scope covers the only industrial dimension (Barle, 2010) compared to the UrS that can optimize the resources consumption into the broadest scale of the city (Vernay et Mulder, 2016); (iii) the functional diversity, by closing the urban metabolic flows, UrS, enables to take advantage not only of the proximity of co-located industries but also of exchanges between various industrial and urban spaces including household, commercial, municipal, industrial activities and urban infrastructures (Van Berkel et al., 2009b; Mulder, 2016). To summarize, the differences between IS and UrS are compared in **Table 1.**

	IS	***UrS***
1. Scale	Industrial park	City

2.	**Objective & Scope**	Optimizing the Industrial Metabolism of Industrial Systems	Optimizing the Urban Metabolism of Urban Systems
3.	**Functional diversity**	Include industrial activities	Include all urban activities

Table 1: Key elements of the difference between IS/UrS

Indeed, considerable environmental benefits have been demonstrated in several IS/UrS pioneering projects, for example, the Kalundborg Symbiosis in Denmark (Chertow & Lombardi, 2005; Jacobsen, 2006), Eco-city projects in Japan (Van Berkel et al., 2009a; H. Dong et al., 2014), the Hammarby model in Sweden (Suzuki et al., 2010). Several studies have demonstrated the *IS /UrS* performance in reducing energy use and CO_2 emissions, as well as on industrial parks scale as on a city scale (L. Dong et al., 2016). Referring to recent scientific contributions (cited in the column of sources), **Table 2** below presents the gains in energy use and CO_2 emissions from some of the most documented international experiments.

Symbiosis	Gains in Energy use	Reduced CO2 emissions	Source
[1] Kalundborg IS - Denmark	30 000 tons of fossil fuels/year	130 000 tons CO_2/year	Ehrenfeld & Chertow, 2002
[2] Kawasaki UrS –Japan	-	4,26 Mt CO_2e/ year	H. Dong et al., 2014
[3] Ulsan IS/U$_r$S – Korea	136 333,4 toe/ year	486 665,1 tons CO_2/ year	Kim et al., 2018
[4] Guiyang IS/U$_r$S –China	18864 tce/an	49046 tons CO_2/year	Fang et al., 2017
[5] Taranto IS -Italy	170 82 toe/ year	1660,90 tons CO_2e / year	Notarnicola et al., 2016

Table 2: UrS/ IS Performances in energy optimization and CO_2 emissions reduction

However, up to date IS/UrS have not yet been integrated into Algeria's urban planning process. That despite the strategic policies introduced by the Algerian central authorities for the country's sustainable development in the fields of national territory development management, natural resources preserving and climate change mitigation as documented in various strategic planning tools (PNAE-DD, 2002; SNAT, 2010; INDC, 2015; PNC, 2019) and several laws related to water, energy, waste management, urban green spaces, local finances, local governance, etc. However, their operational implementation at the local scale remains constrained by the current sectoral approaches. They have not been incorporated into any territorial strategic frame.

2.2. Planning by UrS in the light of Algerian sustainable development policy

We find UrS strategy to be of particular interest to Algeria. Its implementation at the local urban scale provides, indeed, a strategic framework for intersectoral coordination able to respond to the country's strategic policies. The solutions it provides have an obvious potential for preserving natural resources and reducing waste. More specifically, for the management of solid waste, that constitutes today one of the prevalent challenges in achieving Algeria's sustainable development goals. With the increase in waste amounts (MEER, 2018), substantial investments were carried out in recent years, but their management remains far from being efficient (GIZ, 2019). To date, waste recovery rates are just 7%, and disposal in landfills and Technical Landfill Centers TLCs are the main options for handling the bulk of the waste. Moreover, with the lack of efficient facilities and processes, local communities still find tremendous difficulties in collecting, transporting, and recycling (GIZ, 2014). Only 46% are treated in TLCs or controlled landfills, 54% are dumped in raw landfills, when 41% of the population remains underserved by treatment facilities (AND, 2017). Organizing waste sorting and citizens' awareness are no longer addressed in this context (GIZ, 2014).

However, central authorities show a desire to pave the groundwork for a new recovery-based waste management model (MEER, 2019). In this case, setting up the UrS strategy for solid waste valorization in Algeria could contribute to attempt the main environmental goals. Urban planning has a significant role in implementing such a strategy at the local urban scale. Its regulation tools enable reserving suitable areas for urban activities and organizing space such that physical proximity remains possible (Lorrain et al., 2018). It is also the urban planning that enables programming the energy production, waste management, sharing facilities, and organizing exchange networks between urban activities.

3. Conceptual framework of the study case identification and analysis

To define the system to be studied, this article uses the case of a local urban territory in Algiers, by applying a systemic approach. This territory is considered as a complex *urban ecosystem*. The systemic approach is the conceptual framework allowing its knowledge in its global context, understanding its functioning, and determining its purpose (Le Moigne, 1994; Durand, 2017).

3.1. Systemic modeling

The systemic approach takes shape with *modeling*. From a theoretical point of view, according to (Repetti, 2004; Desthieux, 2005), an urban system can be determined by (i) *its boundaries,* the border that ensures its separation from its outer environment and enables the input and output flow crossing (in our case it corresponds to the administrative limits of the inter-municipal territory EH-OS in Algiers); (ii) *its internal structural complex organization* constituted of subsystems composed of physical elements and interrelationships' networks; (iii) *its functional organization:* a set of functional links between the different elements structuring the system, which can be linear or circular and carry various kinds of input and output flows. The cumulative interaction determines the general system functioning: circular links involve feedback that can be positive (when the effect reduces the cause, or when the effect amplifies the cause allowing the system evolves towards a new state), or negative (when the combination of positive and negative effects is regulatory and leads at an equilibrium point); (iv) *its evolution:* a system is a dynamic element that evolves and adapts to its environment; (v) *its purpose or objectives* towards which the system dynamics tends (Le Moigne, 1994; Desthieux, 2005; Durand, 2017). Thus, the application of the theoretical systemic model, defined and illustrated in **[Figure 2]**, refers to the definition of our urban study system elements, represented in **[Figure 4]**.

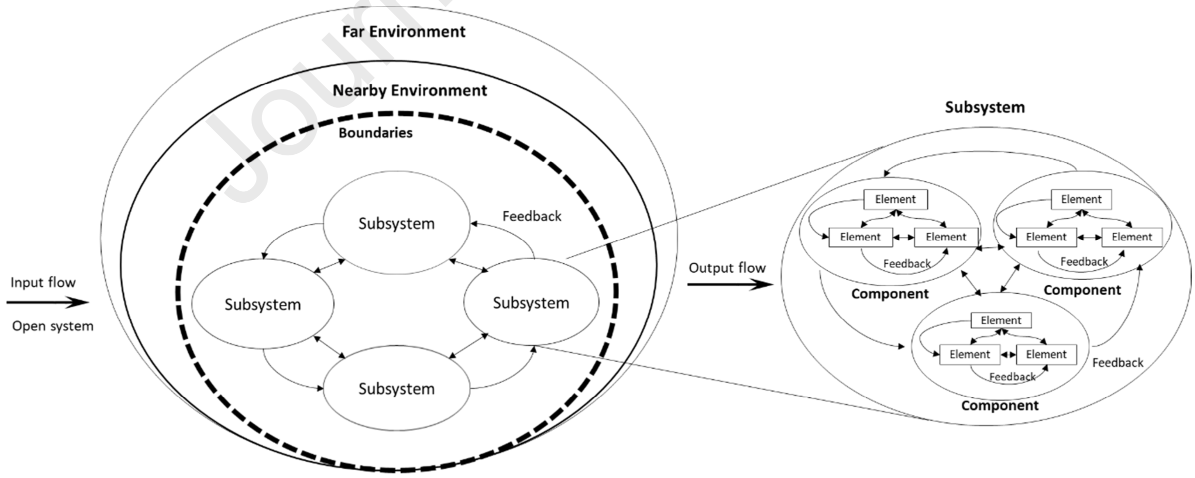


Figure 2: Systemic modeling theoretical elements (Adapted from Repetti, 2004; Desthieux, 2005)

3.2. Algiers's EH-OS local territory: background information

The study urban ecosystem perimeter covers an inter-municipal territory that occupies two municipalities, *EH&OS*, belonging to El Harrach administrative district (daïra)[2], Algiers East **[Figure 3.a]**. With an area of around 17.95 km², a resident population reaching 85 472 inhabitants in 2015, and a significant productive activity in Algiers Wilaya, boosting its economic vocation at the metropolitan and national scales (Berezowska-Azzag et al., 2015). Moreover, its location close to the Algiers major public amenities gives it a metropolitan and international openness and visibility **[Figure 3.b]**. Four urban subsystems (housing, activities, open & green areas, and technical infrastructure) organize its *internal perimeter* **[figure 4.a]**, interconnected by roads and networks that convey input and output metabolic flows. **Table 3** points out the components and elements to consider for each urban subsystem. The map in [**Figure 4.b]** shows the spatial-functional organization of the study system components.

Furthermore, the development *evolution* planned for Algiers by 2035 under the Algiers Master Plan "PDAU" strategic guidelines, places the study area as one of Algiers' major centers **[Figure 4.c]**. A dynamic competitiveness hub intended to accommodate major amenities projects, including Algiers central train station, the new international fair, and the nearby Olympic complex, located near the major university complexes neighbors of the perimeter. Due to these exceptional characteristics, the study area provides suitable conditions for symbiotic proximity search. At the same time, however, a targeted study performed in 2014 at the VUDD laboratory identified it as very faulty in the UM planning and management field (Chaker, 2015)[3] due to a linear metabolism, inducing natural resources over-consumption and large quantities of waste production, as well as a high dependence on fossil fuel. Moreover, *the spatial-functional transformations* planned in the future by the PDAU are likely to increase the pressure on local resources, worsening thus the territory vulnerability to CC. That calls for urgent attention to climate resilience issues in local urban planning and management.

Under these conditions, the system's *purpose* is to induce a resilient local development in energy use and CO_2 emissions. Therefore, it should comply with the national objective of reducing CO_2 emissions by 7%, using the Algiers's Master Plan as a reference framework for its evolution by 2035 (as a time boundary). In this setting, our study is a crucial step in the whole evolution process. It allows planning the necessary urban transformations and estimate the short-term gains for an immediate application. Therefore, sustaining the desired optimal trajectory in the long term will depend on other indicators related to the system's evolution (e.g., economic growth, demography, carbon balance, political choices) (Toubin et al., 2012). The diagram in **[figure 4.c.2]** explains how a planned LC-UrS action could eventually change the CO2 emissions trajectory over the whole urban system's life cycle. The UrS application involves the energy recovery of waste within its local urban perimeter. The waste flow considered in this study relate to the urban solid waste collected in the two municipalities of *EH & OS*. Such wastes relate to Household and Similar Wastes (HSW) that represent the largest share of solid waste in Algeria (50%), 85% of which mainly from the housing subsystem (SDGDI 1, 2012; AND, 2014; Ouamane, 2017; MEER, 2018), where the collection and transport are covered by conventional waste vehicles (trucks) using the already saturated road network.

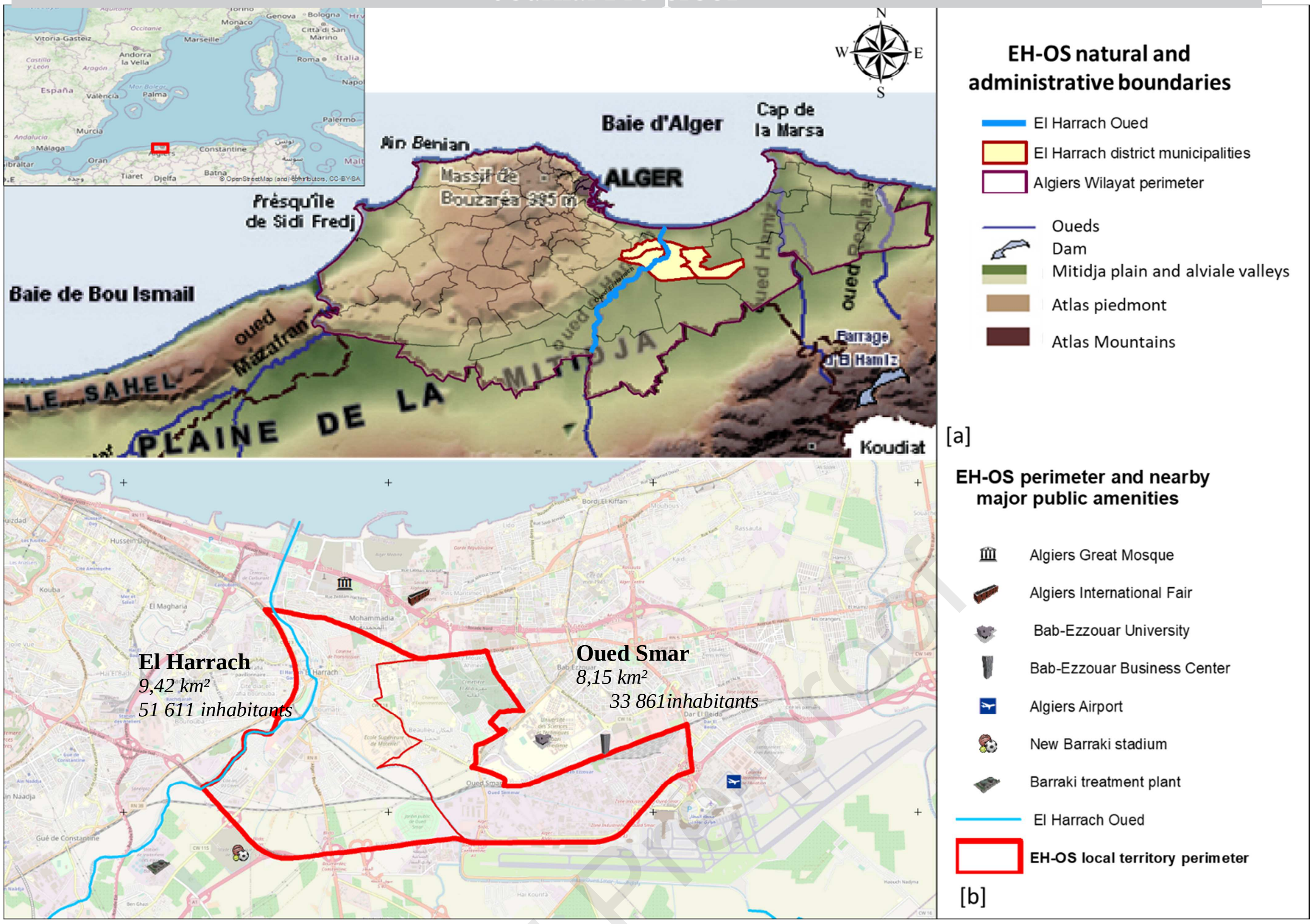


Figure 3: Location and boundaries of the EH-OS perimeter: [a] Natural and administrative boundaries in Algiers context; [b] Spatial-functional boundaries (Sources: MATE, 2005; PDAU, 2016; Basemap: Open street map)

Subsystems	Components	Elements	links' networks
1. Housing	**1.1. Dwellings**	- Individual, semi-collective, collective;	**5. Roads** - Tertiary roads; - Secondary roads; - Primary roads; **6. Various Networks:** - Transport networks; - Information and communication networks; - Drinking water distribution networks; - Energy distribution networks (electric, thermal); - Wastewater drainage networks.
	1.2. Public supporting amenities *	**Nearby basic socio-cultural amenities:** - Shops and services; - Education, worship, culture, media, health, security and leisure; - Nearby public areas (gardens, squares).	
2. Activities	**2.1. Major amenities** *	**Major amenities for the activities :** - **Training and research:** research and higher academic institutions, professional training institutions, laboratories; - **Culture, worship, information and communication:** cultural, religious, communication and exchange amenities; - **Protection:** health, security and justice amenities**;** - **Tourism and leisure:** tourist and sports amenities; - **Transport:** airports, stations, urban stations, relay parking; - **Management and administration:** administrative offices, institutions, office buildings.	
	2.2. Heavy and light industry	**Any kinds of industry: agri-food, paper, textiles, plastics, chemicals, metals.**	
	2.3. Agriculture **	**Any kind of farming.**	
	2.4. Transport	- Individual transport; - Public transport ; - Logistics transport (supply and waste).	
3. Open and green areas	**3.1. Green and blue areas** **	- Parks, forests, gardens, watercourses, rivers;	
	3.2. Large public areas	- Open public areas, squares.	
4. Technical infrastructures	**4.1. Infrastructures and Technical facilities**	- Energy production and storage (cogeneration facility, others); - Drinking water Storage (water tower, water tarp, tanks); - Wastewater treatment (treatment plants, spreading, bio-ecology); - Waste collecting, sorting and pre-treatment (collecting centers, sorting centers); - Waste transforming (incineration and methanization plants); - Funeral infrastructures (cemeteries); - Land (land reserves).	

* The amenities considered in this study relate to the public sector as the private sector involvement remains limited despite the financial and fiscal measures taken to promote the emergence and development of waste reduction and recovery activities (GIZ, 2014).

** In this study, the gains in CO_2 emissions considered for the components of green spaces and agriculture relate solely to symbiotic links, without taking into account the benefits from the CO_2 absorbed through their ecosystem service of climate regulation.

Table 3: Definition of the components, elements, and networks of the Algiers's EH-OS local urban system

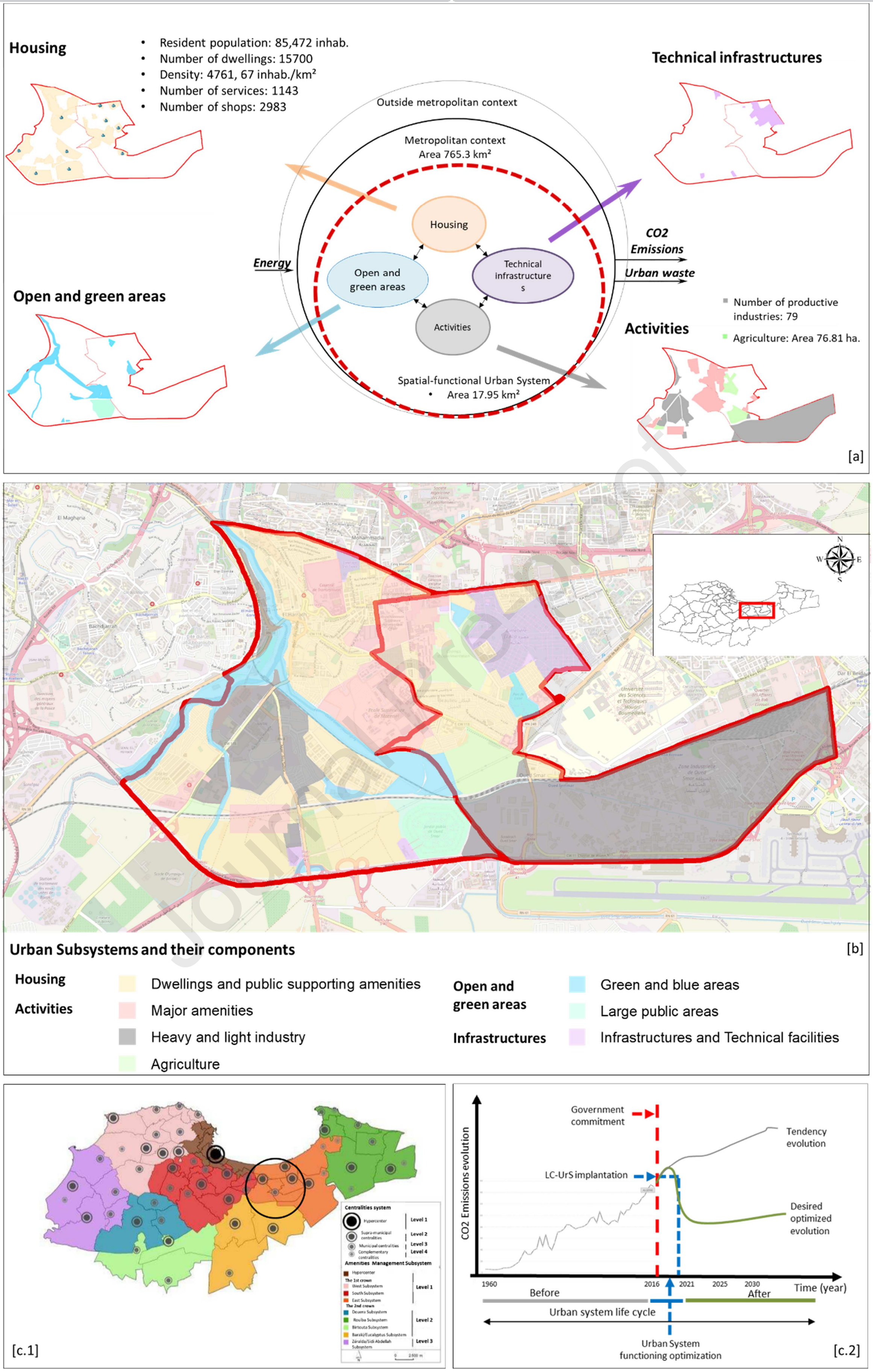


Figure 4: Spatial-functional organization and transformation of the EH-OS Urban perimeter:

[a,b] Identification of the urban subsystems at the EH-OS perimeter according to the systemic model; [c]- Strategic guidelines for the studied perimeter evolution: c.1. EH-OS center territory in Algiers "PDAU" urban centralities system (Sources: PDAU, 2016; Basemap: Open street map).; c.2. Hypothetical diagram of a LC-UrS planned action influence on the evolution of the CO_2 emissions (adapted from Toubin et al., 2012; McDaniels et al., 2008)

4. Exploring Algiers's EH-OS local symbiotic system performance

Since the EH-OS urban system is identified, the methodological approach proposes to explore its performance in energy optimization and CO_2 emission reduction occurs in four stages **[Figure 1]**:

(1) Collecting **data** & elaborating the **database** required for the analysis.

(2) Proposal of a **functional optimization model** allowing identifying the elements and components of potentially promising urban subsystems in symbiotic exchanges, according to the spatial-functional evolutions planned under the Algiers PDAU.

(3) Elaboration of the most likely optimizing **symbiotic scenarios** for the system organization. To analyze the studied UrS's performances for those scenarios, we propose a **quantitative assessment method** able to estimate the gains in energy use and CO_2 emissions for each of them. The option that provides the best outcome is then selected, and **an Urban Symbiosis mapped plan** is proposed for possible support by planning tools.

(4) Checking the capacity to incorporate this analysis outcome in the local urban planning, according to a **methodological framework** outlined to serve as decision support for the local urban programming and spatial-functional planning fields.

4.1. Data collection for the EH-OS local system

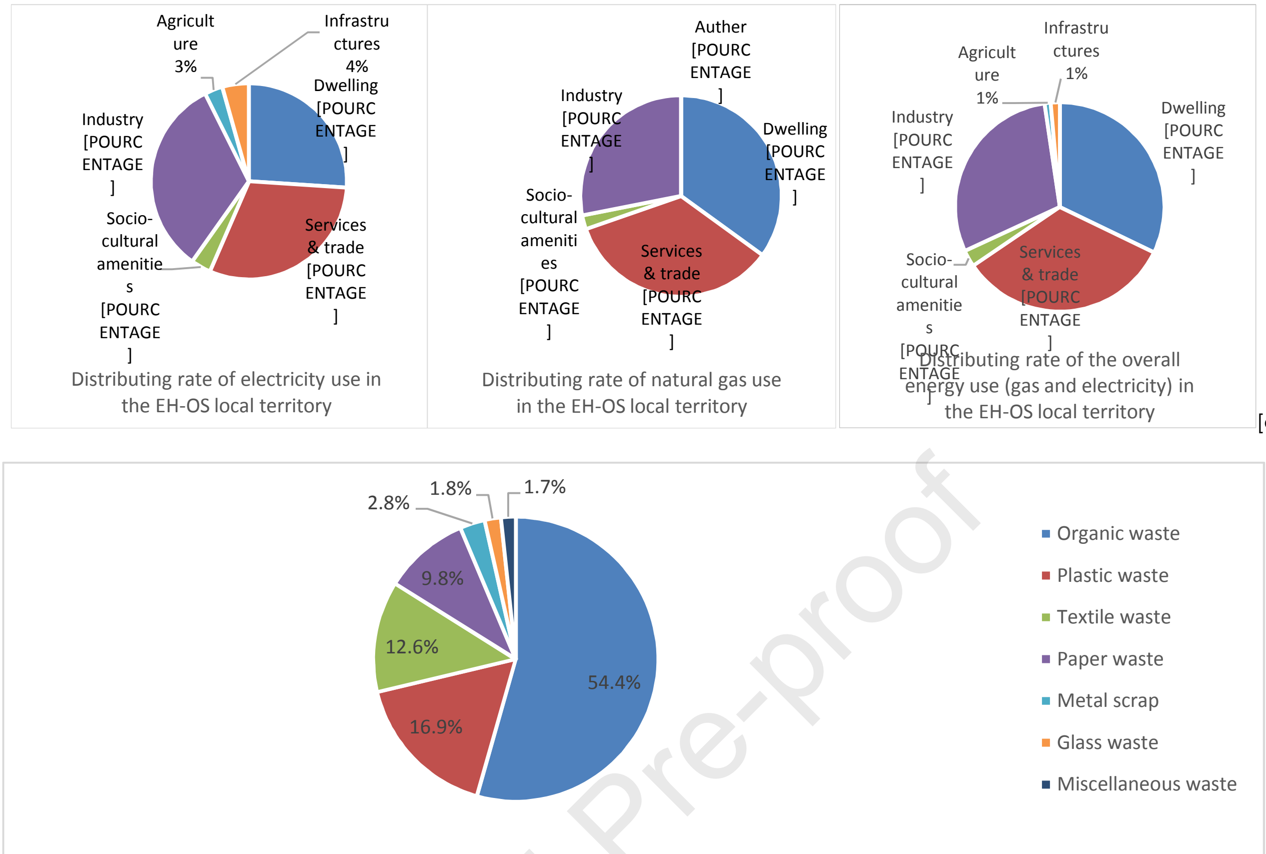
The primary data needed for the system analysis was firstly obtained from an investigation on the used fossil energy and the produced urban solid waste at the studied system. The survey aimed to estimate, on the one hand, the CO_2 quantity resulting from fossil energy use and, on the other hand, the available deposits of waste that can be recovered as secondary resources. **The survey on energy** was carried out using the data obtained from the Algiers Electricity and Gas Distribution Company for the year 2016, and the Sonelgaz report on the national energy balance (SONELGAZ, 2015). Its elements relate to the final consumption of fossil fuel (gas and electricity) from the various urban sub-systems (Chaker, 2021) and the related total CO_2 emissions. **The survey on urban solid waste** was performed according to the data obtained from the National Waste Agency for 2016 and from various documents and reports (SDGDI1, 2010; GIZ, 2014; AND, 2017). Its elements relate to urban waste' categories, quantities, and components that can be valued as renewable energy or secondary material[4] (Chaker, 2021), and how they are collected, transported and treated (AND, 2017).

Furthermore, bibliographic research, devoted to the symbiotic exchange of different practical experiences and theoretical models, was conducted to determine the possible symbiotic links related to waste flow recovery **[Table 4]**, as well as the ratios and reference values needed for estimating the energy optimization potential and CO_2 emissions reduction **[Table 5].**

4.1.1 *Inventory of the input/output flows*

Two input/output flows are of interest within the perimeter of our symbiotic urban system: energy and solid waste, as well as their "carbon effect." Regarding **Energy,** the principal sources used in the study area are natural gas and electricity, distributed respectively at 68% and 32%, out of an overall quantity estimated at 845.6 GWh/year. This consumption is responsible for the emission of 277.8 ktCO_2/year, 68% of which are generated by the housing subsystem. **Figure 5.a** displays the energy use and CO_2 emissions by activity sector. Housing, services & trade, and industry are showing to be the principal energy use sectors.

For **Urban solid waste**, the amount of HSW generated in the study area is estimated at 36 kt/year, of which 85% is collected for treatment. The waste is then transported and treated outside of Algiers Wilaya, at the Corso TLC, at 40 km from the EH-OS territory center, with a rate of 91% of the collected waste (AND, 2017), the rest is discarded into raw dumps or burnt on-site (GIZ, 2014). Only 7-9% of the collected waste is valued in the TLC (AND, 2014; 2017). The composition of urban waste according to the AND data is determined in [**Figure 5.b]**. Organic waste is the category the most produced in the system, followed by plastic, textiles, and paper/cardboard. This waste profile leads the way on the various possibilities of energy and raw materials recovery and bodes well for the positive performance of UrS implementation within this territorial system.



[a]

[b]

Figure 5: The input/output flows at the EH-OS study system: [a] Energy use and CO_2 emissions rates per activity ; [b] Urban waste rates per category (Chaker, 2021 after SDA, 2016; AND, 2016)

4.1.2 *Potential metabolic links for a symbiotic system at EH-OH*

Several possibilities of symbiotic links have been identified to recover the multiple waste flows inventoried above. According to the literature **[Table 4]**, urban waste can be valorized as a secondary material that substitutes the virgin raw material in many agricultural, industrial, construction activities. As a renewable energy source by methanization, incineration, and industrial processes, the different recovery processes of solid waste could be used in the EH-OS system, as presented in [**Figure 6]**.

This preparatory stage helps us explore the EH-OS local symbiotic system's performance that would require, beforehand, designing a model and an evaluation method.

Category of waste	Components	Type of valorization (Secondary material/Energy)	Valorizing activity	Saved consumption resource	Scientific Source
Organic waste	- Food waste: food unfit for consumption (kitchens residues, food industry residues), - Green waste (plants)	- Animal food	- Agriculture	- Agricultural product	SOFIES, 2011
		- Fertilizer	- Agriculture	- Chemical products	Suzuki et al, 2010; SOFIES, 2011
		- Energy: electricity, bio-gas, heat, bio-fuel	- Transformation industry (methanization)	- Fossil fuels	Suzuki et al, 2010; SOFIES, 2011; Massard, 2011
	- Wood waste: sawdust and natural wood shavings	- Material for brick production	- Brick industry	- Inert raw material	SOFIES, 2011
		- Flooring pedestrian paths	- Flooring industry		
Paper waste	- Newspapers, magazines, advertising prints, - Office papers, - Paper and cardboard packaging, - Other	- Recycled paper	- Paper industry	- Wood, virgin fiber pulp, water, energy	H. Dong et al., 2014; Van Berkel et al, 2009
Glass waste	- Glass packaging, - Broken pieces of glass and mirrors, Other glasses	- Recycled glass	- Glass industry	- Inert raw material	FEDEREC, 2017
Plastic waste	- Used plastics	- Insulating material	- Building materials industry	- Inert /or organic material, energy	SOFIES, 2011
	- Mixed plastic waste (plastic containers and packaging)	- Energy: Alternative fuel for cement kiln	- Cement industry	- Coal	Van Berkel et al., 2009
		- Energy: Synthetic gas for the production of ammonia	- Ammonia industry	- Energy (City Gas)	
		- Energy: Heat, electricity	- Transformation industry (incineration)	- Fossil fuels	ADEME, 2019
	- Bottles and flasks	- Recycled plastic	- Plastic industry	- Raw material, energy	FEDEREC, 2017
Metal scrap	- Steel waste	- Recycled steel, - Material for cement production, - Rudimentary material for road construction	- Steel industry, - Cement industry	- Raw material, energy	L. Dong et al., 2016; Notarnicola et al., 2016
	- Aluminum waste	- Substitute for cement production material	- Cement industry		L. Dong et al., 2016
Textile waste	- Used textiles	- Collection, repair, and resale	- Trade	- Raw material, energy	SOFIES, 2011
		- Secondary material for textile production	- Textile industry		FEDEREC, 2017
		- Energy: Heat, electricity	- Transformation industry	- Fossil fuels	

Table 4: Potential recovery opportunities for the different categories of solid urban waste at the local scale (from the literature review)

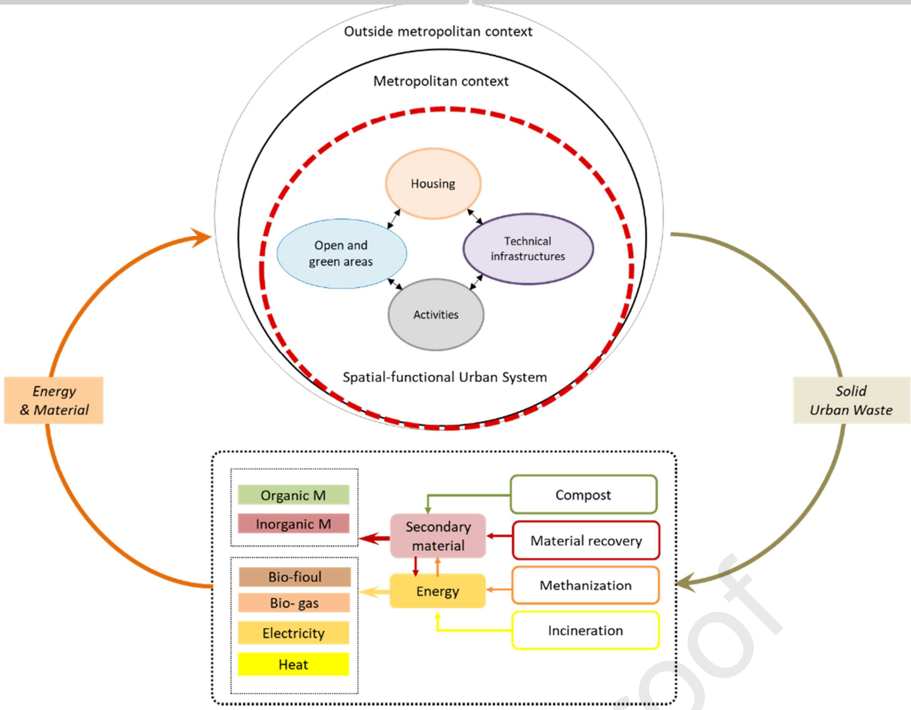


Figure 6: Solid waste recovery processes (according to Chaker, 2015)

4.2. **Description of the local symbiotic system "EH-OS"**

4.2.1 *Conceptual model of the cyclical metabolism for the studied symbiotic system*

In light of the inventoried data and the multiple possible symbiotic links identified, *an optimizing functional model* should be designed for the study context with a set of circular links. That includes the *Waste-Energy* Output-Input flows, in which the different urban subsystems and their components interact. It involves a functional reorganization allowing to mobilize the various systems' elements in a *cyclical metabolic flows process* able to handle both: (i) the produced waste flow collection and transformation; (ii) and in feedback, energy recovery, and its redistribution to consuming activities [**Figure 7.a**]. In this sight, the urban subsystems' elements and components are immediately at the nexus of symbiotic performance needs (Lorrain et al., 2018). Their buildings, road infrastructures, and technical networks are no longer seen as isolated elements but as *"links of a chain inscribed in a larger urban or territorial ecosystem"* (Ray, 2013).

This model supports to reduce the amount of waste produced by urban activities, to preserve the virgin raw material needed to sustain these activities, of course, but mainly to recover energy from different processes **[Figure 7.b]**. It provides four modes of Energy Recovery: (i) *producing* clean and renewable energy through methanization and incineration processes; (ii) *reducing* energy use by recycling energy-intensive materials which avoid energy use and emissions from virgin materials mining and processing during many life cycle stages; (iii) *recovering* waste energy from industrial processes; (iv) finally, *diverting* waste from landfills to local valorizing facilities avoids the transport and treatment impacts in distant areas.

In this way, the model presumes to create new renewable energy sources, which, if reintroduced in the system, could positively affect reducing the used fossil fuel and, consequently, the related CO_2 emissions. Checking its implementation involves analyzing the system performances. The core premise in this model is that any gained energy could reduce the amount of fossil energy used in the metabolic system operating. Thus, it contributes to reducing carbon emissions. However, various combinations of symbiotic links are possible in the EH-OS territory that should first be identified and then analyzed. So, an **assessment method** is proposed below for estimating the symbiotic links performances in the studied urban system.

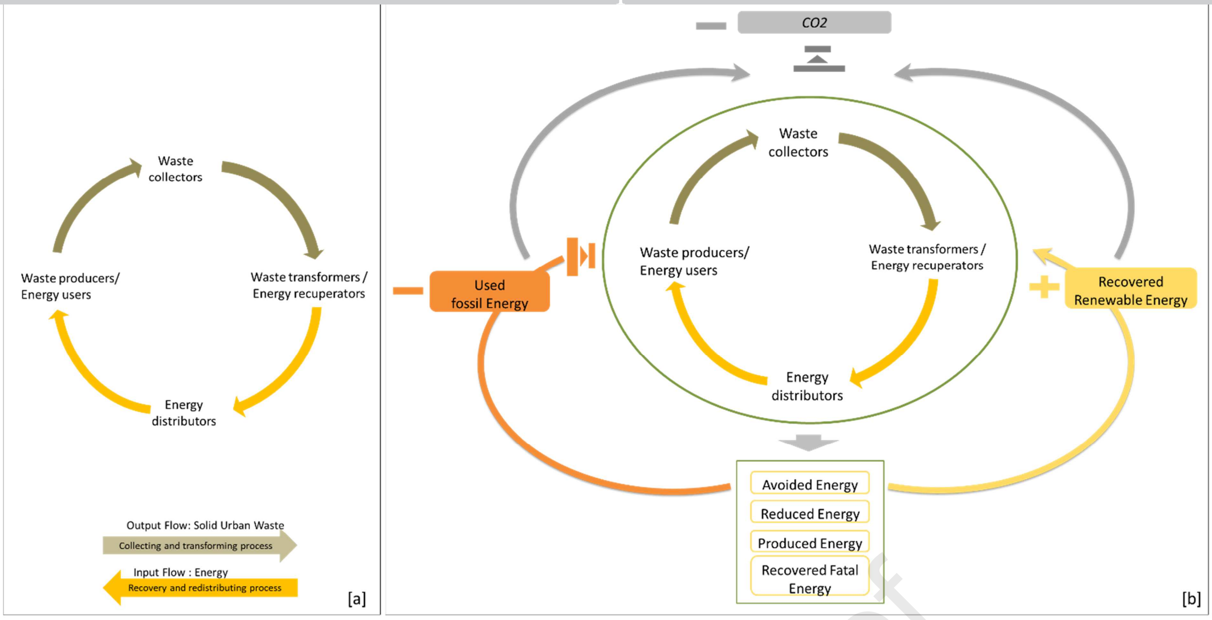


Figure 7: A proposed functional model for optimizing the urban cyclical metabolism system: [a] Functional organization of the system elements based on a cyclical metabolic flows process ; [b] Recovering energy process impact.

4.2.2 *Simulation of the possible UrS scenarios*

Using this model, we need to simulate the most likely optimizing symbiotic scenarios using scenario design's morphological method. For achieving so, *the Waste-Energy cyclical metabolic process* is broken down into five main dimensions according to its modeled steps: (1) the waste flow produced in the system; (2) collection; (3) transport of collected waste to transforming plants; (4) transformation and recovery of energy; (5) distribution of the recovered energy to the applicant subsystems (users). For each dimension, two to four variables are defined. Some possible responses (hypothesis) are formulated for each of them. The scenarios are then developed by combining the established hypothesis for every variable. The morphological space of the possible scenarios simulation is presented in [**Figure A.1, Appendix A**]. The identified scenarios are displayed in **[Figures 10, 11, 13].**

4.3. Symbiotic scenarios performances analysis method

Using Material Flow Analysis (MFA) and Life Cycle Analysis (LCA) methods, this stage aims to quantify the optimized energy and reduced CO_2 emissions in the study context, and then estimate the gains**.** The findings of this analysis are summarized in **section (4.4.1 *infra*).**

4.3.1 *Optimized Energy and Reduced Carbon Emissions under scenario j*

The quantitative evaluation is performed for each scenario by calculating both **optimizing indices**: Optimized Energy (OpEn) and Reduced CO_2 Emissions (ReEm). The OpEn Index refers to the symbiotic links yield in reducing the Used fossil Energy amount (U_f En), by Recovering Energy from valorized waste (R_wEn), which implies a reduction in CO_2 emissions (ReEm). Both key indices ($OpEn_j$)&($ReEm_j$) are determined from the synthetic indicators, indicated respectively in **formulas (1)** &**(2):**

$$\mathrm{OpEn_j} = \mathrm{U_fEn_j} - \mathrm{R_wEn_j} \qquad \textbf{(1)}$$

$$\mathrm{ReEm_j} = \mathrm{GeEm_{(U_fEn)j}} - \mathrm{AvEm_{(R_wEn)_j}} \qquad \textbf{(2)}$$

Where j: index number of a scenario; U_fEn_j [GWh/year]: Used fossil Energy; R_wEn_j [GWh/year]: Recovered Energy from valorized waste; $\mathbf{GeEm_{(U_fEn)j}}$ [ktCO_2e/year]: Generated CO_2 Emissions from Used fossil Energy; $AvEm_{(R_wEn)_j}$ [ktCO_2e /year]: Avoided CO_2 Emissions by recovering Energy from valorized waste. **Figure 8** summarizes the calculation principle.

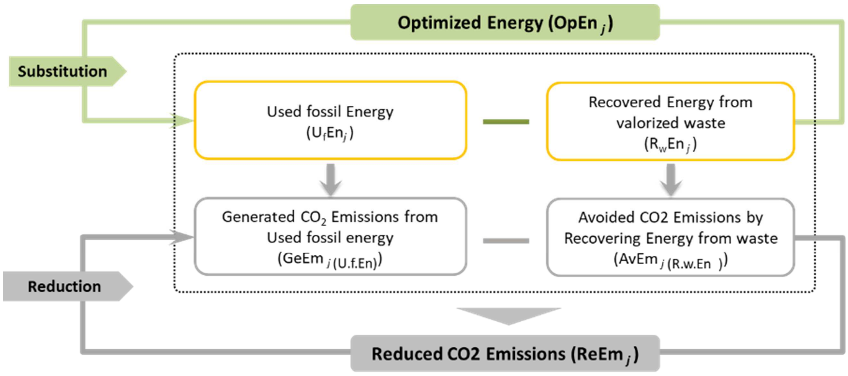


Figure 8: The principles of symbiotic optimizing scenarios assessment

The synthetic indicators calculation is based on previous studies' results. **Table 5** below summarizes all the ratios used and their corresponding data sources. We will detail, hereafter, the calculating method.

A. Used fossil Energy and related Emissions

Used fossil Energy $U_f En_j$ is the energy required to operate the symbiotic urban system under a scenario j. It is calculated using three indicators:

(i) **Direct consumed Energy** $D_{cons}En_j$ [GWh/year], is the amount of fossil energy (gas and electricity) consumed directly in the local study system (for heating, cooling, domestic hot water, lighting, industrial processes, others.).

(ii) **Indirect mobilized Energy** $I_{mob}En_j$ [GWh/year], is the amount of fossil energy mobilized in collecting and transforming process of the produced waste amount. It is determined from the three process stages: collection, transport, and treatment ($En_{collection\ j}$, $En_{transport\ j}$, $En_{treatment\ j}$), according to the selected treatment mode under a scenario j (landfill, incineration, methanization, recycling).

(iii) **Gray embodied Energy** $G_{emb}En_j$ [GWh/year], is the amount of energy embodied in the processes of implementing treatment facilities, required for a scenario j (build a new treatment center, its extension, new networks and equipment, others).

$U_f En_j$ can be calculated, for each scenario, from **formulas (1.1)&(1.2)**, of which:

$$U_fEn_j = D_{cons}En_j + I_{mob}En_j + G_{emb}En_j \quad \textbf{(1.1)}$$

$$U_fEn_j = (elec_j + gas_j) + \alpha_j * [(\beta_1 * D_{avg}C + \beta_2 * D_{trip}\,T * {}^{n}/_{c}) * Qw_j + \gamma_j * \textstyle\sum_w(\mho_{(m,w)j} * Qw_j) + \varepsilon * \gamma_j * \sum_x Qw_{x,j}\,] \quad \textbf{(1.2)}$$

Where $elec_j$ [GWh/year]: the total annual amount of electricity consumed in the study system; gas_j [th/year]: the total annual amount of natural gas consumed in the study system; Qw_j [t/year]: the annual amount of waste produced in the study system; α_j : waste collection rate; γ_j : treatment rate; $Q_{collected}\,w_j$ [t/year] : the annual amount of collected waste; $Q_{treated}\,w_j$ [t/year] : the annual amount of treated waste, according to the category and treatment mode; β1 [l/km]: fuel consumption per kilometer for urban waste collection with stops; $D_{avg}C$ [km/t]: average Distance to collect one ton of waste; β2 [l/km]: fuel consumption per kilometer for the transport of waste to treatment areas; $D_{trip}T$ [km /trip]: the distance between collecting and treatment location for one transport trip of the collected waste amount; n is the number of trips per truck to dump and return; c [t] is the transport truck capacity in terms of weight; $\mho_{(m,w)j}$ [KWh/t] : average energy use per ton of treated waste according to the treatment mode (m) and the waste category (w); ε [KWh/t] : Energy rate needed for implementing a new treatment facility per ton of treated waste; $Qw_{x,j}$ [t/an] : the annual amount of waste treated by the facility x. The detailed calculation formulas are given in section **B.1 in Appendix B.**

It should be noted that energy use units would be converted to [KWh]. Furthermore, Generated CO_2 Emissions from Used fossil Energy $GeEm_{(U_fEn)j}$ are determined, under each scenario j, using $CO_{2(D_{cons}En)_j}$, $CO_{2(I_{mob}En)_j}$, $CO_{2(G_{emb}En)_j}$ indicators, corresponding respectively to Used Energy indicators **(formulas 1.1&1.2)**. They are calculated from **formulas (2.1)&(2.2)**, of which:

$$GeEm_{(U_fEn)j} = CO_{2(D_{cons}En)_j} + CO_{2(I_{mob}En)_j} + CO_{2(G_{emb}En)_j} \quad \textbf{(2.1)}$$

$$GeEm_{(U_fEn)j} = elec_j * EF_{elec} + gas_j * EF_{gas} + \left(En_{collection\ j} + En_{transport\ j}\right) * EF_{transport} + \sum_w (Q_{treated} w_{(m)j} * EF_{treatment\ (w,m)}) + G_{emb}En_j * EF_{G_{emb}\ En} \quad \textbf{(2.2)}$$

EF is the Emission Factor corresponding to the form that takes the used energy source. These factors are presented in [**Table 5]** below, and the detailed calculation formulas are given in section **B2- Appendix B.**

B. Recovered Energy and related Avoided Emissions

Recovered Energy from valorized waste (R_wEn_j) is determined using the indicators:

(i) **Avoided Energy for consumption ($AvEn_j$),** by diverting waste from landfills to local recovery industries;

(ii) **Reduced Energy ($MiEn_j$),** through *recycling* energy-intensive materials, refers to the Energy used to produce virgin raw material.

(iii) **Produced Energy ($PrEn_j$),** heat & electricity produced from organic waste methanization or organic, paper, and plastic waste incineration.

(iv) **Recovered Fatal Energy ($FaEn_j$),** recovered heat from industrial processes of waste valorization.

(v) **Lost Energy ($LoEn_j$)** in electricity or heat delivery networks, as losses in pipes, in substations, and others.

R_wEn_j can be calculated, for each scenario, from **formulas (1.3)**&**(1.4),** of which:

$$R_wEn_j = \sum\left(AvEn_j + MiEn_j + PrEn_j + FaEn_j\right) - LoEn_j \quad \textbf{(1.3)}$$

$$R_wEn_j = \text{¢} * Q_{treated} w_j + \sum_w (\text{ɽ}M * Q_{recycled} w_j) + [\sum_w (\text{þ}_{(m,w)} * Q_{treated} w_j) + \upsilon * \sum_w (\text{Ʊ}_w * Q_{treated} w_j)] * (1 - \mu) \quad \textbf{(1.4)}$$

Where ¢[KWh/t]: Energy use rate per one ton of landfilled waste according to scenario 0; ɽM [KWh/t]: Energy recovery rate by recycling one ton of waste, of a category (w), as a secondary material, it corresponds to the average energy use for producing one ton of virgin raw material (M); $Q_{recycled}\ w_j$[t/year]: the waste amount, of a category (w), recycled as secondary material; $\text{þ}_{(m,w)j}$ [KWh/t]: rate of renewable energy production per ton of waste treated according to the waste category (w) and the treatment mode (m); Ʊ_w [KWh/t]: Energy use rate per one ton of waste, of a category (w), recycled as a secondary material; ʋ (%): the average rate of waste heat to be recovered; µ (%): the average rate of loss in networks (of produced and fatal energy). The detailed formulas are given in **section B.3 in Appendix B.**

Avoided CO_2 Emissions $AvEm_{(R_wEn)j}$ are determined, under each scenario j, using $AvCO_{2(AvEn)\ j}$, $AvCO_{2\ (MiEn)j}$, $AvCO_{2\ (PrEn)j}$, $AvCO_{2\ (FaEn)\ j}$ indicators, referring respectively to Recovered Energy indicators R_wEn_j **(formulas 1.3&1.4)**. They are calculated from **formulas (2.3)**&**(2.4)**, of which:

$$AvEm_{(R_wEn)j} = \sum(AvCO_{2(AvEn)j} + AvCO_{2(MiEn)j} + AvCO_{2(PrEn)j} + AvCO_{2(FaEn)j}) - AvCO_{2(LoEn)j} \quad \textbf{(2.3)}$$

$$AvEm_{(R_wEn)j} = \text{ȼ} * Q_{treated} w_j + \sum_w (\text{ɘ}_w * Q_{recycled} w_j) + [\sum_w (\text{Ə}_{(m,w)} * Q_{treated} w_j) + FaEn_j * EF_{elec}] * (1 - \rho) \quad \textbf{(2.4)}$$

Where ¢ [ktCO_2e/t]: CO_2 emission rate per one ton of landfilled waste according to scenario 0; ɘ$_w$ [ktCO_2e /t]: the average rate of Avoided CO_2 emissions per one ton of waste, of a category *(w)*, recycled as secondary material; Ə$_{(m, w)}$ [ktCO_2e /t]: the average rate of Avoided CO_2 emissions per one ton of waste, of a category *(w)*, recovered as renewable energy according to the treatment mode (*m*); $EF_{elec:}$ Emission Factor related to electricity production from fossil sources for the recovered fatal energy; ρ: rate of CO_2 emissions losses related to the energy lost in delivery networks. The detailed formulas are given in section **B4-Appendix B.**

Used fossil Energy $U_f En_j$					**Generated CO_2 Emissions from Used fossil Energy** $GeEm_{(U.f\ .\ En)\ j}$			
Form of energy	**Rate**	**Value**	**Unit**	**Source**	**Rate**	**Value**	**Unit**	**Source**
Direct consumed Energy ($D_{cons}En_j$)	elec	-	-	-	EF_{elec} (Algeria)	0.548	kgCO_2e / kWh	[2] ; [4]
	gas	-	-	-	EF_{gas}	0.227		[2]
Indirect mobilized Energy ($I_{mob}En_j$) for waste collection and transport *	β_1	0.605	l/km	[1]	EF_{fuel}	2.66	kg CO_2e/l	[5]
	$D_{avg}C$	11,4	km/t	[1]				
	β_2	0.427	l/km	[2]				
	c	25	t	[2]				
Indirect mobilized Energy ($I_{mob}En_j$) for waste treatment	Ʊ $_{landfill}$	6.77	l/t	$\frac{EF_{landfill}}{EF_{fuel}}$	$EF_{landfill}$	18	kgCO_2e/ t	[2]
	Ʊ $_{methanization}$	30.84	kWh /t	$\frac{EF_{Methanization}}{EF_{gas}}$	$EF_{methanization}$	7	kgCO_2e/ t	
	Ʊ $_{incineration}$	79.30	kWh /t	$\frac{EF_{Incineration}}{EF_{gas}}$	$EF_{incineration}$	18	kgCO_2e/ t	
	Ʊ $_{paper\ and\ cardboard\ recycling}$	2763.5	kWh /t	[3]	$EF_{paper\ and\ cardboard\ recycling}$	467.6	kgCO_2e/ t	[3]
	Ʊ $_{plastic\ recycling}$	1534			$EF_{plastic\ recycling}$	187.6		
	Ʊ $_{metal\ recycling}$	3660			$EF_{metal\ recycling}$	916		
	Ʊ $_{glass\ recycling}$	100			$EF_{glass\ recycling}$	24,2		
	Ʊ $_{textile\ recycling}$	6.5			$EF_{glass\ recycling}$	7,7		
Gray embodied Energy ($G_{emb}En$)**	ε	32.85	kWh /t	Calculated	$EF_{G_{emb}\,En}$	18 0.548	kgCO_2e/ t kgCO_2e/ kWh	[2]

Recovered Energy from valorized waste R_wEn_j				**Avoided CO_2 Emissions by Recovering Energy** $AvEm_{(R.w.\ En)}$		
Form of energy	**Rate**	**Value (kWh/t)**	**Source**	**Ratios**	**Valeur (kgCO_2e/t)**	**Source**
Avoided Energy	¢	$I_{mob}En_0$ / $Q_{treated}W_0$	Calculated	¢	$CO_2(_{I.mob.En})_0/Q_{treated}W_0$	Calculated
Reduced Energy ($MiEn_j$)	ƮM $_{paper\ and\ cardboard}$	11154	[3]	ɘ $_{paper\ and\ cardboard}$	343.50	[3]
	ƮM $_{plastic}$	15496.5		ɘ $_{plastic}$	1449	
	ƮM $_{metal}$	6248		ɘ $_{metal}$	2211	
	ƮM $_{glass}$	1716		ɘ $_{glass}$	594	
	ƮM $_{textile}$	27241		ɘ $_{textile}$	5608	
Produced Energy ($PrEn_j$)	þ$_{(methanization,\ organic\ waste)}$	170 kWh élec + 340 kWh therm	[8]	Ə$_{(methanization,\ organic\ waste)}$	44	[2]
	þ$_{(incineration,\ organic\ waste)}$	119 kWh elec + 527 kWh therm	[2]	Ə$_{(incineration,\ organic\ waste)}$	11 elec part + 147 therm part	[2]
	þ$_{(incineration,\ paper\ waste)}$	340 kWh elec + 1505,5 kWh therm		Ə$_{(incineration,\ paper\ waste)}$	66 elec part + 946 therm part	
	þ$_{(incineration,\ plastic\ waste)}$	766 kWh elec + 3392 kWh therm		Ə$_{(incineration,\ plastic\ waste)}$	29 elec part + 419.5 therm part	
Recovered Fatal Energy (FaEnj)	ʋ	**Retained value 12%** (between 0% and 24%)	[6]	-	-	-
Lost Energy ($LoEn_j$) ***	μ	**Retained value 10%** (between 8% and 12%)	[7]	ρ	10%	-

* Based on the ADEME data, we consider that the fuel consumed for waste collection (β1) is higher than its transport (β2) due to the numerous collection stops.

** Inventories related to Gray embodied Energy $G_{emb}En$, to its emissions $CO_{2(G_{emb}En)_j}$, and the lifespan of building materials and processes are not available. ADEME (2019) offers a value of 18 kg CO_2e / per ton of waste to build treatment centers, which corresponds to an electricity use equivalent to 32.85 KWh /ton of treated waste.

*** μ, the loss rate for a sufficiently dense and very well maintained network.

Sources: [1] ADEME, 2014 ; [2] ADEME, 2019 ; [3] FEDEREC, 2017 ; [4] IEA, 2013; [5] Ressources naturelles Canada, 2014; [6] Panayiotou et al., 2017 ; [7] MEFI, 2006 ; [8] Planète Energie, 2014.

Table 5: Ratios and reference values for the optimizing potential calculation

4.3.2 *Potential gains estimation*

Gains are evaluated from both partial **Symbiotic Performance Indices** (SPI), $En_{Gain j}$ and $CO_{2\ Gain\ j}$, calculated, for each scenario, compared to the basic "0" scenario, from formulas (1.5), (2.5) of which:

$$En_{Gain\ j} = \mathrm{U_f En_0} - \mathrm{OpEn_j} \quad \textbf{(1.5)}$$

$$\mathrm{CO_2}_{\ Gain\ j} = \mathrm{GeEm_{(U_f En)0}} - \mathrm{ReEm_j} \quad \textbf{(2.5)}$$

Where $En_{gain\ j}$ [GWh/year]: Energy gain; $CO_{2\ gain\ j}$ [ktCO_2e /year]: CO_2 emissions gain.

The two indices are then estimated for each scenario, compared to a reference value based on the national CO_2 emissions reduction target of 7%, using the Multi-Criteria method. Thus, they are interpreted on a scale from 0 to 5 divided into five levels at equal intervals **[Figure 9]**. The maximum index value corresponds to the highest score of the scale. The scoring is the lower for the minim value. The scenario that offers the best result in energy and carbon gains (global SPI) could then be proposed for support by urban planning tools. Global SPI is considered a ratio between energy gains and carbon emission gains. It is measured by aggregating the partial indexes on a scale of 0 to 10**.**

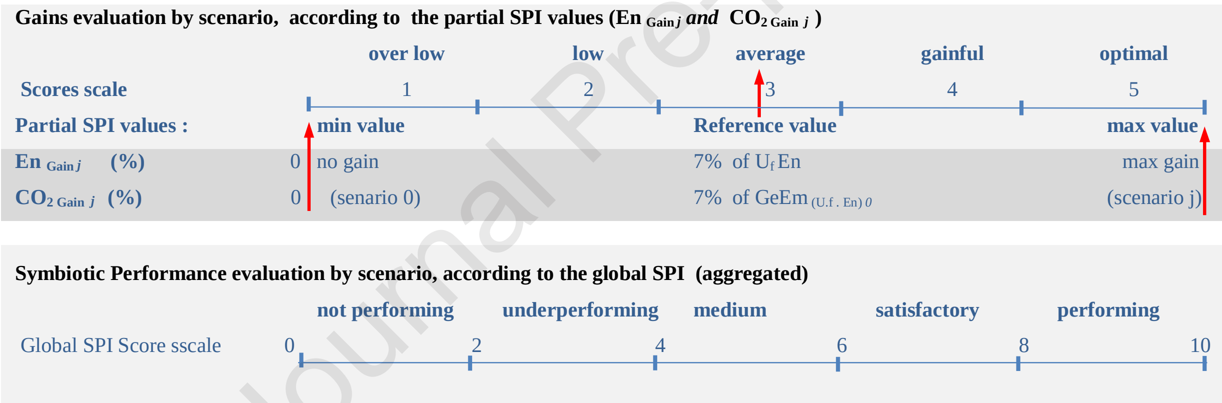


Figure 9: Evaluation method of Symbiotic Performance Index (SPI)

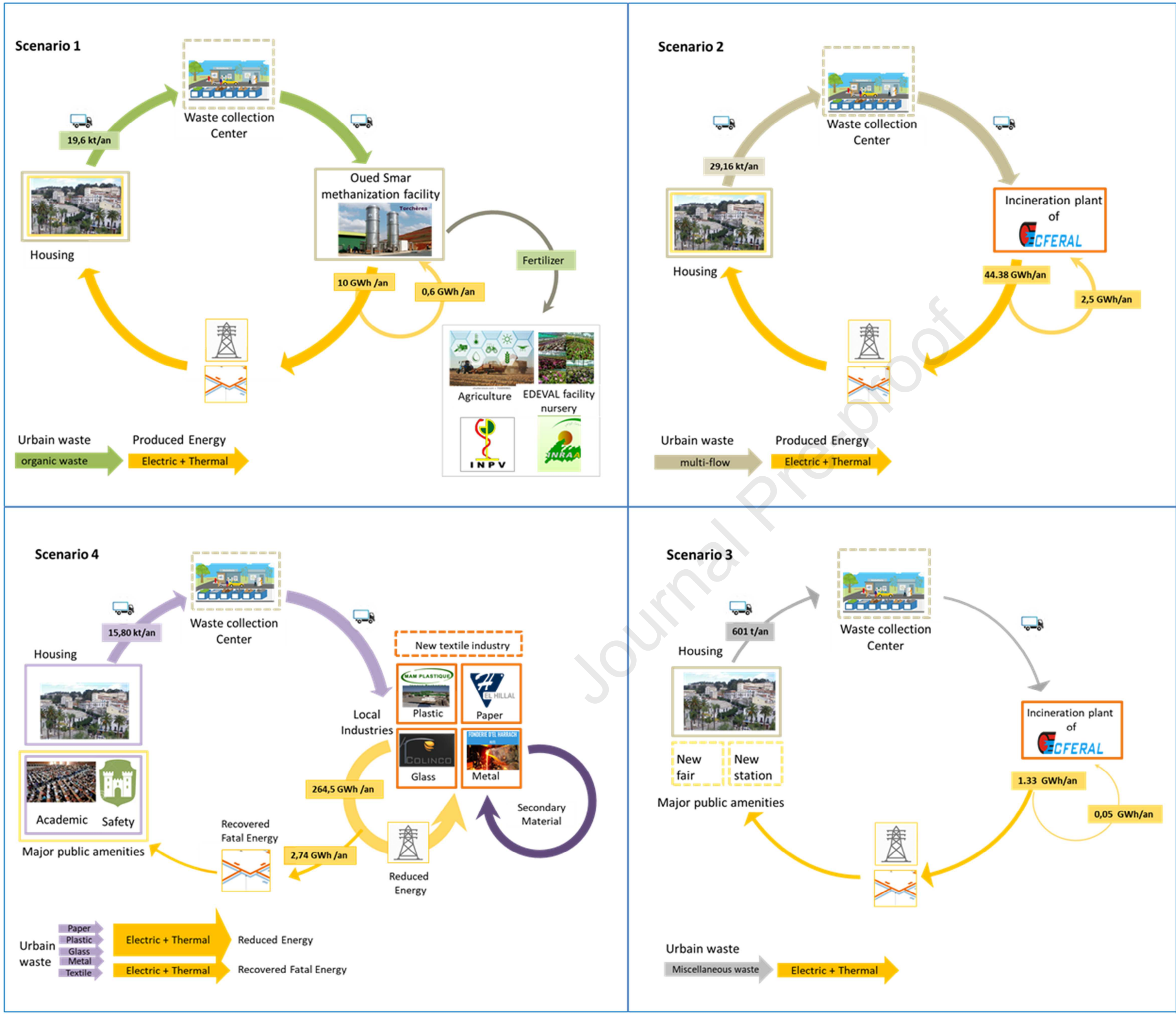
4.4. **Application of the method and results**

4.4.1 *Systemic Analysis of the EH-OS territory symbiotic scenarios*

Based on the data recorded in **tables [3, 4**] and **figures [5,6]**, the analysis of the *Waste-Energy cyclical model* **[figure 7]** allowed us to determine the key elements for Energy Recovery in different forms. Like this, the potential of Recovered Energy and avoided CO_2 emissions were both estimated, then the urban planning actions needed to transform the system could be identified. The following sections explain in detail the systemic analysis elements.

A. Symbiotic Scenarios for EH-OS system

Five symbiotic scenarios have been developed compared to an initial scenario j_0 (no symbiotic activity), which represents the current state of the system defined in **[Figures 4** and **section (4.1.1.)]** *supra*. The operation of this scenario, based on linear UM, involves the waste collection in multi-flow, then their transport to the Corso TLC, for landfill. This scenario determines the starting point for a future UrS implementation. The other scenarios combine the different hypotheses related to the *Waste-Energy cyclical metabolic process*, for which we assume that all waste is treated locally with a collection and recovery rate of 100%. That involves building a waste collection facility for selective collection and pre-treatment. The traveled distance to collect waste is determined on the assumption that one truck should drive 11.4 km to collect one ton of urban waste (ADEME, 2014). The four scenarios (1 to 4) are presented in **Figure 10**, and **Figure 11** illustrates the 5th one, which combines the (1,3,4) scenarios.



Scenarios description

Scenario 1 foresees extending the biogas recovery facility of the Oued Smar former disposal to a methanization facility. It involves a selective collection of organic waste for energy (electric and thermal) production. This energy will be, used in the Housing subsystem for several uses (heating, kitchen, lighting) with a recovery of 6 % for the methanization facility operation. Fermentation residues are also, used as a fertilizer in agriculture, either in the EDEVAL facility nursery for green space development or in the INRA agricultural research institute and the INPV plants' protection institute.

In scenario 2, the total amount of urban waste is collected in multi-flow to be transferred, to ECFERAL's incineration plant, with the recovery of the produced energy (electric and thermal). 7% of which would be used to fuel the incineration facility. The major part would be intended for the housing subsystem, replacing thus, 8% of the used fossil energy.

Scenario 3 involves a selective collection of the only non-recyclable miscellaneous quantities for their energy-recovery incineration. 4% of which would be used to power the incineration plant. The major part would be for the nearby major public amenities, including the new international fair and the new international station.

Scenario 4 provides for the selective collection of paper, plastic, textile, and metal waste, for recycling in the selected local industries. This scenario requires building a textile processing industry. The fatal energy recovered from the various recycling processes would be used to replace fossil fuel in academic, health, and safety public amenities.

Figure 10: Graphical presentation and description of the symbiotic scenarios (j1, j2, j3, j4)

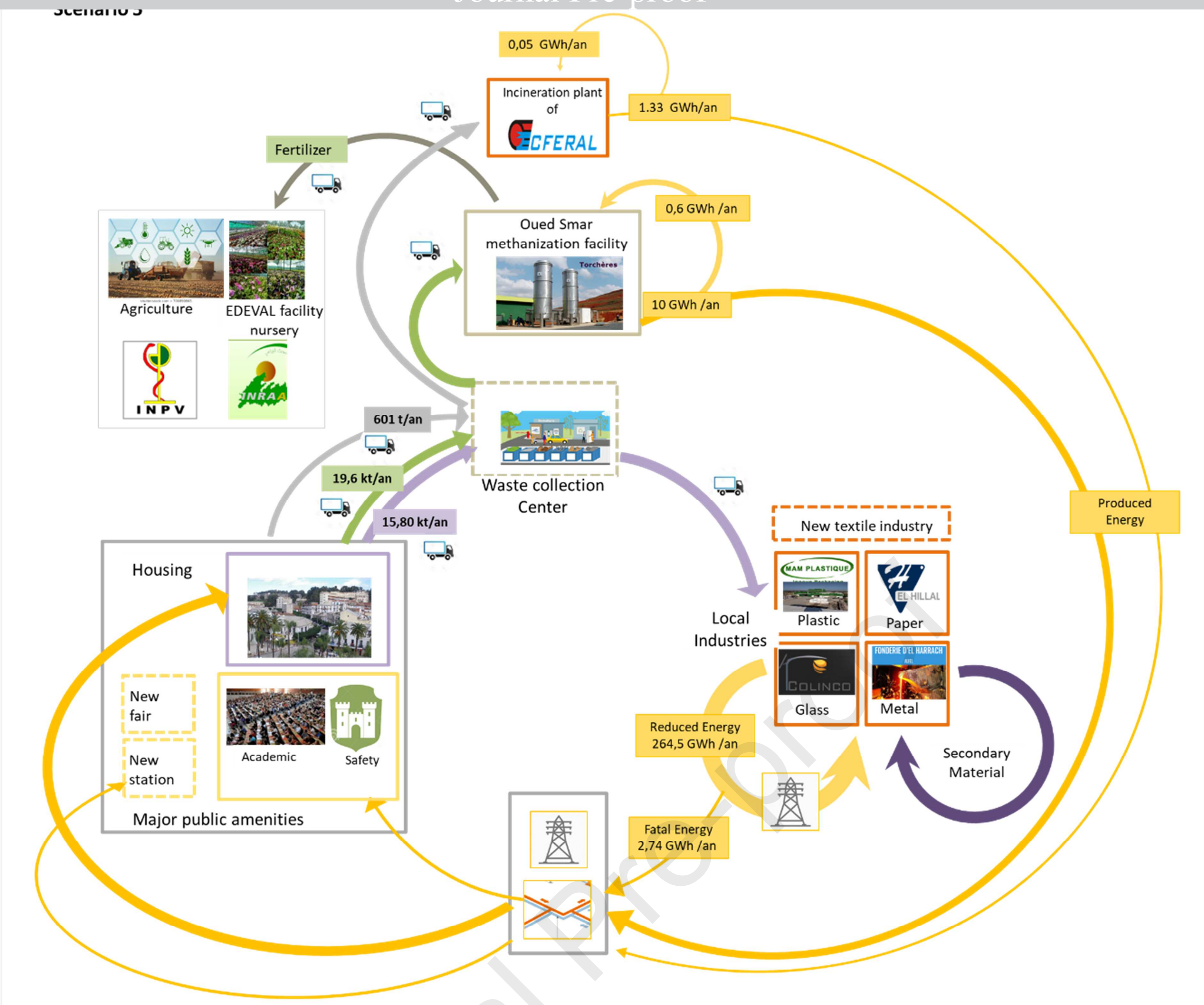


Figure 11: Graphical presentation of the symbiotic scenario (j5) as a combination of three other scenarios (j1, j3, j4)

B. Key functional elements for symbiotic links

The main functional elements identified to create symbiotic exchanges at the study system, their activities, buildings, and infrastructures are described **in Table 6** below, and located by the map in [**figure 14.a, section 4.4.2]** hereafter, according to the results of the estimated carbon gains.

System elements	Description
Producers/ Users	- **The housing subsystem,** it constitutes both the largest share of produced waste (85%) and consumed energy in the system. Therefore, it is a significant source of renewable energy whose recovery could meet, in return, its demand. - **The various major public amenities** (academics, health, safety, and the significant projects of Algiers central station and international fair planned for 2035) are also potential elements in the symbiotic links.
Collectors	- **A waste collection center** is proposed instead of the municipal pound to take over the collection, pre-treatment, and waste transport to the transformer elements. That helps improve the urban symbiotic system operation**.**
Transformers	- **Industrial activity** is also a potential for valorizing these resources at the EH-OS local system. Some industries already developed recycling activities, such as ALFEL and ECFERAL[5] companies. *Moreover, several* other companies could probably be involved in transforming the different recyclable waste categories (plastic, paper, glass, metals) into secondary material. However, recycling textile materials would imply implementing a textile industry in the study system. - **The biogas recovery facility** (from the Oued Smar former dump), a plant with an extraction capacity of 5000Nm³/h (Sweepnet, 2010), which can recover biogas. However, its operation in urban waste methanization would involve expanding networks and installing new equipment.

Table 6: **Description of the key elements of the EH-OS Urban Symbiosis**

C. *Potential Energy recovery and estimated carbon gains*

Energy Production. In the EH-OS local context, operating the methanization plant allows producing 10 GWh/year of energy, thereby preventing 861 tons of CO_2, for the available waste quantity **(scenarios.j1&j5)**. Besides, with the contribution of ECFERAL Company, two possibilities for waste incineration are offered: (i) incinerating the whole plastic, paper, and organic waste, which allows producing 44.38 GWh/year of energy and avoids 10,81kt CO_2e for the available amount **(scenario 2)**; (ii) incinerating only the non-recyclable miscellaneous waste, which allows producing 1.33 GWh/year of energy and avoids 324.2 t CO_2e, for the available amount **(Scenarios j3&j5).**

Energy Reduction. Recycling plastic, textile, paper, and metal waste in the selected EH-OS industries allows reducing 264.48 GWh /year of the energy used for virgin material production. To this end, we estimate the following transforming potentials for the available waste quantities **(scenario j4&j5)**:

(i) Plastic waste for producing packaging in the MAM Plastic firm, for example, allows an energy reduction estimated at 94 GWh/year. It avoids the emission of 8.8 ktCO_2e/y;

(ii) Textile waste in the textile industry for producing textile packaging, rags, carpets, others, allows reducing 123.7 GWh /year and avoids 25.45 ktCO_2e/y;

(iii) Paper waste in the ELHILAL paper industry, for producing recycled paper, allows reducing 39.13 GWh /year and avoids 1.2 ktCO_2e/y;

(iv) Metal waste in the ALFEL industry allows reducing 6.39 GWh/year and avoids 2.26 ktCO_2e/y;

(v) Glass waste in the COLINCO industry, for glass production, allows reducing 1.14GWh/year and avoids 339.23 tCO_2e/y.

Fatal Energy Recovery. An estimated Fatal Energy of 2.74 GWh/year could be recovered from the secondary material recycling in the various local industries, indicated above **(scenario j4&j5)**. That allows avoiding the emission of 1.5 kt CO_2e for the collected waste amount.

Avoided Energy. Transforming waste locally helps to avoid the energy used for transport and treatment beyond the EH-OS context. This Energy estimating depends on the Energy used under each scenario [**Tables 4, C.1, C.2]**.

The quantitative evaluation of the different scenarios allows us to determine the symbiotic performances of the system. **Figure 12** illustrates the optimized energy and reduced CO_2 emissions potential under each scenario and illuminates the gains. **Table 7** presents the global SPI estimation of each scenario according to the comparative gains results. The detailed results are given **in Appendix C**.

Among the proposed scenarios, the preliminary morphological analysis simulation shows a preferential trend towards scenario 5 **[Figure 13]**, which offers the optimal result in energy and carbon gains **[Table 7]**. However, selecting one option depends on multi-stakeholder consultation in a participatory urban planning process. That involves numerous decisions relating to its legal and regulatory feasibility, financial and land availability, and the social, economic, and environmental impact of urban development solutions. We will sketch, below, some of these spatial-functional solutions.

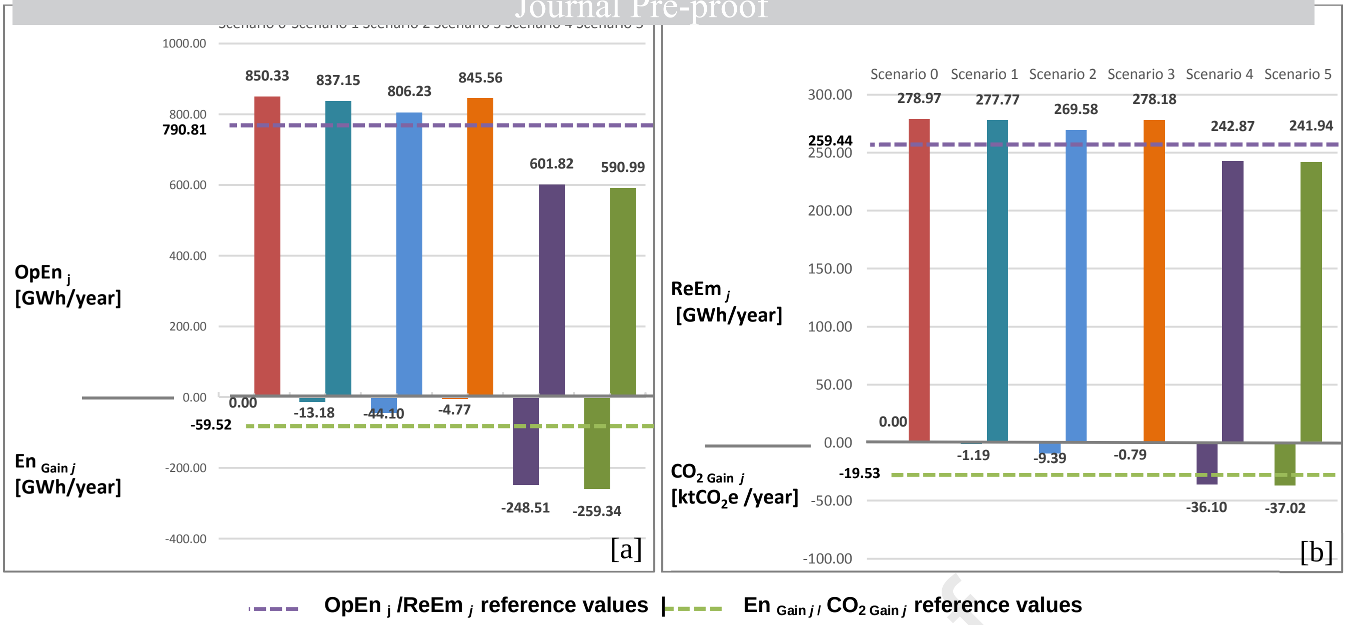


Figure 12: Gains quantification results under each scenario: [a] in Energy use, [b] in CO_2 emissions

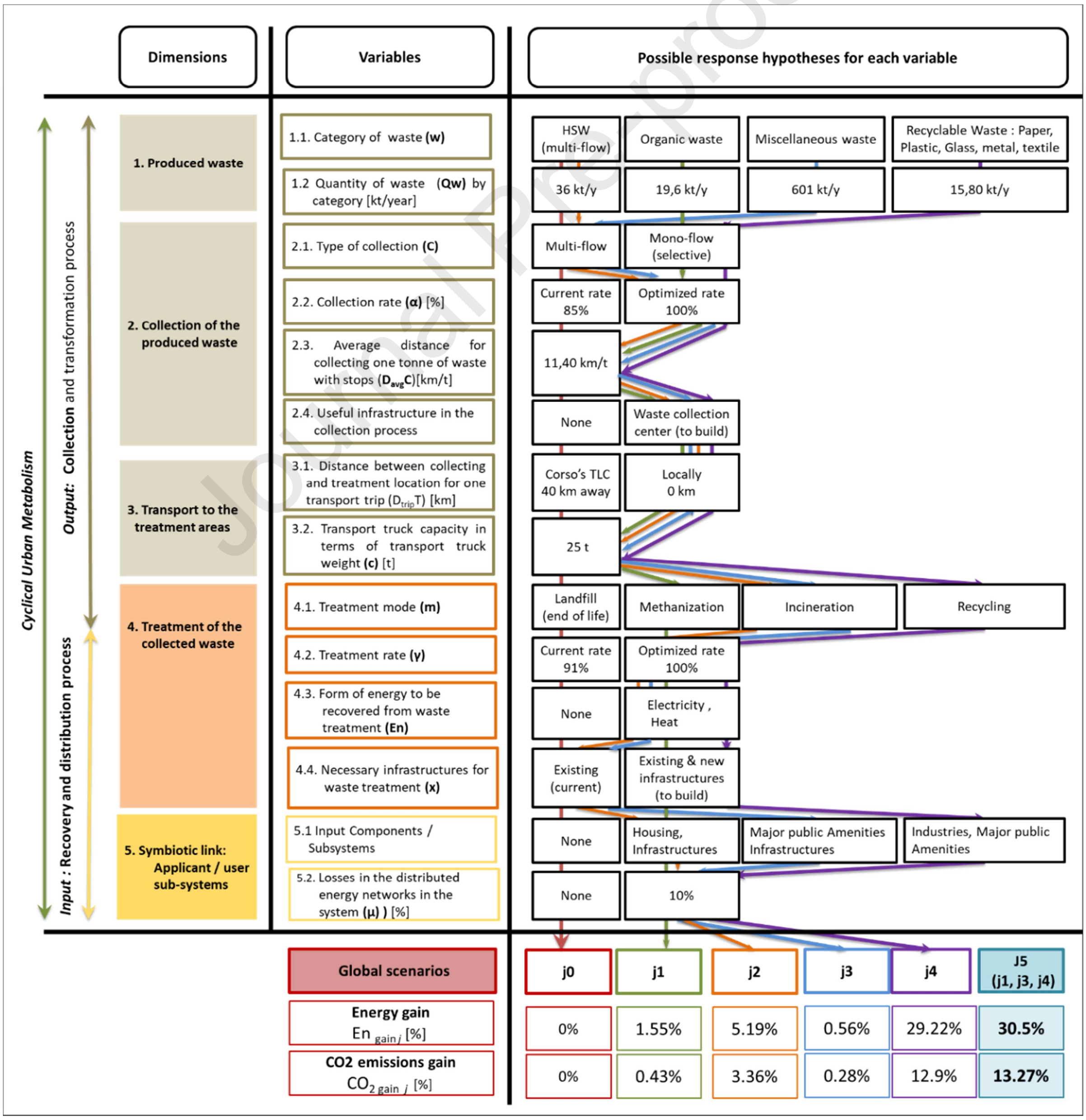


Figure 13: The morphological analysis simulation results

Scenarios j (0-5)	Energy Gain Reference value (7%)			CO$_2$ Emissions Gain Valeur de référence 7%			Symbiotique performance	
	Value (%)	Score		*Value (%)*	Score		SPI Score	
j0	0%	0	*no gain*	0%	0	*no gain*	0	not performing
j1	1.55%	1	*over low*	0.43%	1	*over low*	2	underperforming
j2	5.19%	2	*low*	3.36%	2	*low*	4	medium
j3	0.56%	1	*over low*	0.28%	1	*over low*	2	underperforming
j4	29.22%	5	*optimal*	12.9%	5	*optimal*	10	performing
j5	30.5%	5	*optimal*	13.27%	5	*optimal*	10	performing

Table 7: Results of gains evaluation and SPI estimation under each scenario

4.4.2 *Spatial visualization of the estimated gains*

This study's findings could be spatially interpreted by the proposal of a LC-UrS scheme for the urban territory development strategy [**Figure 14.b].** Translating this scheme into an urban design plan according to the optimal selected scenario implies highlighting beforehand some constraints and requirements, which are discussed below.

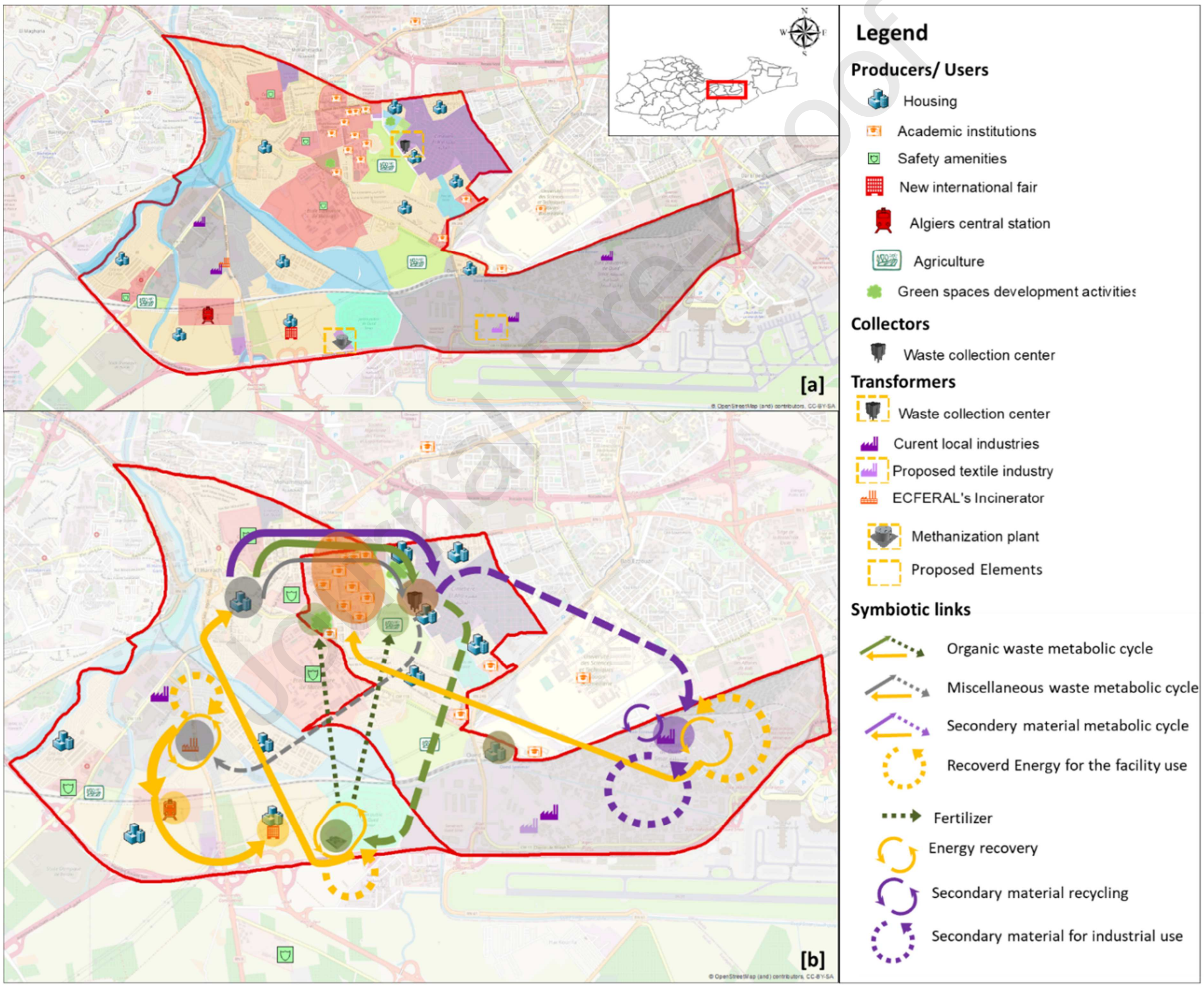


Figure 14: Proposal for a mapped LC-UrS local plan at the EH-OS local territory (Open street Basemap).

[a] Location of the Urban Symbiosis elements and components at the EH-OS local territory ; [b] Scheme of the LC-UrS under scenario j5

4.5. **Discussion and local development policy implications**

For the case-study system EH-OS, we have examined five Symbiotic Scenarios **[Figures 10, 11].** The results show that applying an UrS can significantly optimize energy use and reduce CO_2 emissions.

Two features are common to all the studied system's scenarios: (i) fossil energy use is the main contributor to CO_2 emissions; (ii) waste diversion from burying at the Corso's TLC toward the local recovering helps to reduce far transport distances and consequently avoids energy consumption and related CO_2 emissions. **Scenario j4** findings show that waste recycling in local industries is a successful contributor to reach the strategic targets, unlike **Scenario j2,** where the produced energy contributes only to a low reduction **[Tables 7, C1, C2].** Furthermore, **Scenarios (j1&j3)** help to produce renewable energy (electric and thermal) from waste valorization. Although their contribution is low, compared to **Scenario j4**, they offer other advantages for waste management. Incineration in **Scenario j3** is the most suitable solution for managing the miscellaneous (no recyclable) waste amount. The organic waste methanization in **Scenario j1** generates a fertilizer for agriculture and green space development activities.

Compared to the basic scenario j0, **scenario j5** gives an optimal total gain in Energy and CO_2 Emissions estimated at 259,34 GWh/year and 37,02 ktCO_2e/year that represent 30,5% and 13.27% per year of the current consumption and emissions . The Recovered Energy is obtained from: (i) producing 11.32 GWh/year of clean Renewable Energy in methanization and incineration processes; (ii) reducing 264.5 GWh/year of Energy use by recycling secondary materials in local industries; (iii) recovering 2.74 GWh/year of waste energy from industrial recycling processes;(iv) finally, diverting waste from the burial site to the local recovering facilities avoids 6.1 GWh/year for transport and treatment in distant areas. The Avoided Carbon Emissions from this whole cyclical process are estimated at 42,06 ktCO_2e/year.

Besides its symbiotic performance, the scenario j5 presents also other advantages, related to preserving non-renewable natural resources, saving land meant for landfills, reducing the costs of faraway waste transport, economic gainfulness thanks to the energy and raw material preservation, as well as job creation in local industries. In this sight, the buildings, infrastructures, and networks, which are the links of the urban symbiosis chain (Ray, 2013), are also a vehicle for introducing innovations by their equipment in intelligent technical systems: automated collecting by robotic vehicles, automated heat and lighting management systems, energy production, waste sorting (Lorrain et al., 2018). The shift towards innovative collection and sorting technologies, such as the underground automated vacuum network or the drone special green corridors, could offer an attractive alternative to traditional collection in improving the living environment (e.g., reduced traffic problems and related CO_2 emissions, improved safety and hygienic levels) (Kaliampakos et Benardos, 2013).

Therefore, this scenario involves several urban planning and urban design actions, including: (i) reserving land to build a new collection center for fostering a separate waste collection; (ii) extending the methanization and incineration facilities and the necessary networks enabling to promote the development of renewable energy production activities; (iii) programming new activities (industrial, commercial, and craft activities) for the textile products recycling; (iv) planning the urban developments and equipment enabling the selective collection in the respect of the urban carrying capacity; (v) planning the possible decentralized separated network for energy management; (vi) developing a local decentralized energy management system; etc. That calls for a feasibility and impact studies from an economic, environmental, social, technical, and regulatory perspective and risk evaluation. It is also necessary to verify the long-term socio-economic cost-effectiveness for inhabitants, industries and municipalities.

Moreover, implementing such a strategy would require background conditions. (i) Firstly, an environmental policy that should promote the development of symbiotic links by integrating into its priorities the looping of material and energy flows as a principle for natural resource preservation, waste management, and climate change mitigation (Lorrain et al., 2018; Massard et al., 20114). (ii) Secondly, a socio-economic policy that should promote the waste recovery industry and encourage creating new recycling companies on the one hand and, on the other hand, should support the inhabitants in reducing their energy consumption and CO_2 emissions. Besides, waste sorting and green space maintenance require households' participation, which calls for awareness and education actions to facilitate the local population's mobilization in symbiotic urban projects (Lorrain et al., 2018; Massard et al., 2014). (iii) The third condition relates to local public authorities. Given their unique position as a local administrative level, they have a triggering role in implementing UrS, particularly by integrating economic actors and civil society, establishing inter-sectoral and inter-municipal collaboration in urban activity sectors, mobilizing all human and materials resources, and the innovative technological tools to promote efficient monitoring and evaluation of symbiotic projects. (iv) Indeed, this could not be achieved without the national government's support, which should play a significant role in establishing a conducive legal system, that can help exceed all environmental constraints, reinforce the financial means of projects, and facilitate their supervision at the local level (Lorrain et al., 2018; Massard et al., 20114).

However, these conditions are not yet developed in the field in Algeria, and our system has to face several constraints, like for example: (i) socio-economic, with increasing demand for housing, amenities, and infrastructures, hard to meet in a context of an economic crisis, lack of project financing resources, and scarce urban land; (ii) environmental, including water stress, the threat of energy crisis, exposure to natural disasters, and extreme climatic events (between floods, drought, high winds, and storms, food insecurity, etc.); (iii) legal and organizational, with the inefficiency of public action, the absence of appropriate legislative and regulatory tools, the lack of specialized technical and human resources, and the absence of a collective approach (Berezowska-Azzag et al., 2015a; Berezowska-Azzag, 2015b). All of this hinders UrS strategy implementing in the Algiers local context.

The encouraging aspect is that the Algiers Master Plan (PDAU) strategic vision strives to materialize a new policy for transforming Algiers into an eco-metropolis. It acknowledges that interactive urban issues are complex and cannot be addressed using the same methods currently in use. It proposes so a strategic approach aimed to direct the Algiers' local urban development (PDAU, 2016). Adopting the LC-UrS strategy, as part of the Algiers PDAU, could support the three pillars of this plan relating to Economic development, Territorial cohesion and to the Environment protection and enhancement, that covers natural resources preservation, energetic transition, integrated waste management, urban activities development including housing, trade, industrial, agricultural, socio-cultural, educational, of scientific and technological research, as well as infrastructures and networks, through integrating several specific structuring projects **[Figure 15.a]**[6].

Nevertheless, implementing these projects in the territorial model (pillar 5) as a strategic orientation tool lacks consistency in the action levels hierarchy, by operating on an ad hoc and autonomous manner and moving directly top-down from the strategic to the operational level. For this purpose, *a LC-UrS Local Plan* could be integrated at an intermediate level for the inter-municipal scale considering, networking the Algiers future projects in a symbiotic development prospect **(Figure 15.b)**. As a coordinating filter, it would be able to organize and develop the metabolic loops by planning the required urban activities and infrastructures for the benefit of Energy optimization and CO_2 emissions reduction in the inter-sectorial way.

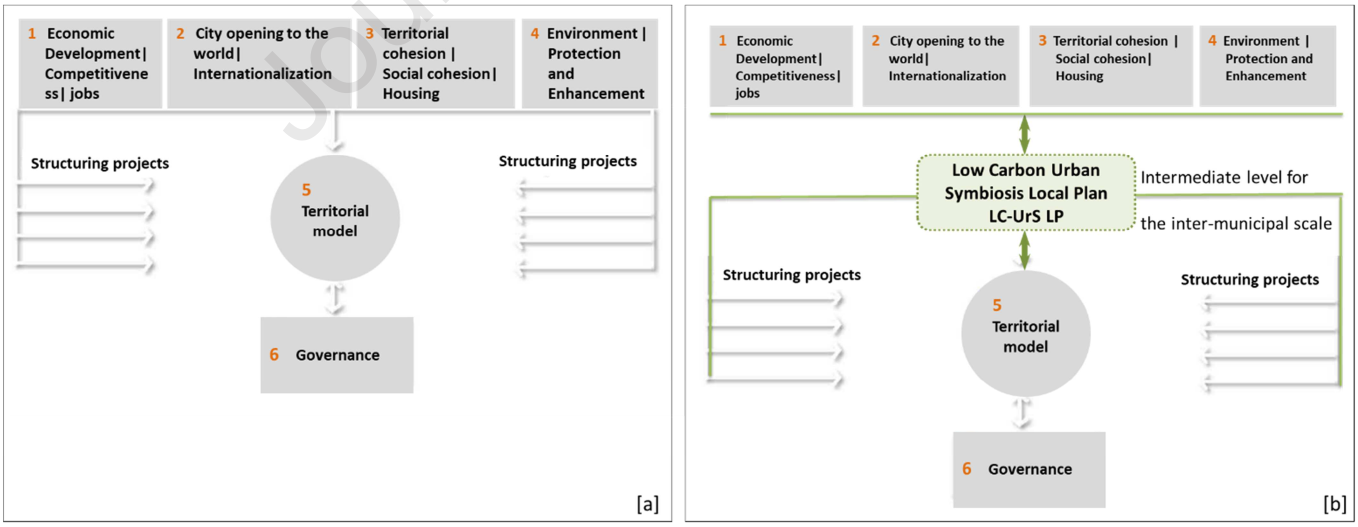


Figure 15: Possible incorporation of a LC-UrS Local Plan into the Algiers PDAU: [a] The six pillars of the Algiers PDAU strategic approach (source: PDAU, 2016); [b] The LC-UrS Local Plan as an intermediate strategic level in the PDAU framework

Furthermore, the PDAU opens up to integrating new methods and tools for programming, urban planning, urban design, and decision support. To this end, supporting the UrS strategy in the planning process would mean exploring ways for its incorporation in Algeria's urban planning tools.

5. Conclusion

IS/UrS present considerable optimizing potential demonstrated in several IS/UrS pioneering projects. Referring to the international scientific literature, this paper explored the UrS performances in Algiers local urban context for the operational urban planning needs, focused on CO_2 emissions mitigation. Using a systemic approach, the study conducted to the urban symbiosis planning proposals in one local urban system with a high potential of urban activities, considering *the Waste-Energy cyclical metabolic process.* By valorizing urban waste into renewable energy, we proposed symbiotic links between different urban subsystems (housing neighborhoods, public amenities, industrial activities, and technical facilities), then evaluated their performances in optimizing Energy use and reducing CO_2 emissions. The results highlighted the symbiotic exchange potential of the local study area and revealed an estimated optimal gain of 30.5% and 13.27% per year in Energy consumption and CO_2 emissions in this intercommunal territory. Therefore, it stands out that looping metabolic flows between various urban activities within the broadest framework of urban projects provide effective solutions beyond the IS scope limited to industrial parks. That brings interesting answers for the Algerian urban managers to reduce Algeria's GHG and achieve the climate resilience objective, if the main Algerian metropolitan cities join the common urban symbiotic national policy. Their potential to contribute to the global CC mitigation effort seems proportional to their urban capital in terms of housing, structural facilities and logistic networks, but also to their capacity for managing the local public action, searching various investment sources and valorizing local knowledge.

Broader implementation at the national level could then help to reach the 7% target, and even more. Hence, this optimizing potential from UrS will be even more significant for all countries, particularly with the increase in urban waste. So, implementing UrS should be encouraged in other cities around the world, where housing neighborhoods, public amenities, industrial activities, and technical facilities coexist. Thus, we hope our study contributes a lot to the international knowledge share, particularly in developing countries.

However, we have seen that implementing such a strategy would require background conditions. Thus, the prospect for integrating the UrS into the local urban planning process first entails a comprehensive identification of the local political conditions, therefore defining the most appropriate implementation tools, then checking the long-term economic profitability for households, companies, and locality. These issues will be developed in our next contribution.

6. Acknowledgments

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7. References

ADEME., 2014. Base Carbone : Documentation des facteurs d'émissions de la Base Carbone ®. Version 11.Agence de l'Environnement et de la Maitrise de l'Energie. 18 novembre 2014. https://www.bilans-ges.ademe.fr/

[dataset] ADEME., 2019 . Base Carbone : Documentation des facteurs d'émissions de la Base Carbone ®. Version 16. Agence de l'Environnement et de la Maitrise de l'Energie. 29 avril 2019. https://www.bilans-ges.ademe.fr/

AND., 2014. Caractérisation des déchets ménagers et assimilés dans les zones nord, semi-aride et aride d’Algérie. Agence Nationale Des Déchets AND. https://and.dz/publication-du-rapport-de-la-campagne-de-caracterisation-de-2014/

AND., 2017. Rapport sur la gestion des DMA dans la Wilaya d’Alger. Agence Nationale Des Déchets AND , Mai 2017. https://and.dz/publication-rapport-gestion-dma-wilaya-dalger/

APRUE., 2017. Consommation énergétique finale de l’Algérie : Chiffres clés année 2015. Alger : Ministère de l’Énergie et des Mines, Agence Nationale pour la Promotion et la Rationalisation de l’Utilisation de l’Énergie APRUE.

http://www.aprue.org.dz/documents/PUBLICATION%20CONSOMMATION%20ENERGETIQUE%20FINALE%202015.pdf

Barle, S., 2010. ‘Écologies urbaine, industrielle et territoriale’. *in* Coutard O., Lévy J.-P. (dir.), Ecologies urbaines, Paris, Economica-Anthropos, 61-83. https://www.economica.fr/livre-ecologies-urbaines-coutard-olivier-levy-jean-pierre-c2x32210639

Berezowska-Azzag, E., Abdelatif I., Akrour N., Bouallag-Azoui O., & Srir M., 2015. Baromètre des performances urbaines locales : Alger et ses communes. Editions Alternatives urbaines, Alger. https://www.academia.edu/27561605/Barom%C3%A8tre_des_performances_urbaines_locales_Alger_et_ses_communes

Berezowska-Azzag E., s/d., 2016. Le climat dans tous ses états. Laboratoire Ville Urbanisme et Développement Durable VUDD in Newsletter n°2, mars 2016. EPAU. http://www.epau-alger.edu.dz/index.php/labo-de-recherche/v-u-d-d/newsletter/174-newsletter-n-2-climat

Boons, F., Chertow, M., Park, J., Spekkink, W., Shi, H., 2017. Industrial Symbiosis Dynamics and the Problem of Equivalence: Proposal for a Comparative Framework. J. Ind. Ecol, *21*(4), 938-952. https://doi.org/10.1111/jiec.12468.

Chaker, M., 2015. La démarche d'écologie industrielle appliquée au contexte local à Alger pour une planification et une gestion responsable du métabolisme urbain. École Polytechnique d’Architecture et d’Urbanisme EPAU, Alger. https://epau.academia.edu/MaziaCHAKER

[dataset] Chaker, M, 2021. Energy and waste data for the Algiers's EH-OS local system . Mendeley Data. http://dx.doi.org/10.17632/wsz69rzsjw.1

Chen, X., Fujita, T., Ohnishi, S., Fujii, M., Geng, Y., 2012. The Impact of Scale, Recycling Boundary, and Type of Waste on Symbiosis and Recycling: An Empirical Study of Japanese Eco-Towns. J. Ind. Ecol,16(1), 129-141. https://doi.org/10.1111/j.1530-9290.2011.00422.x.

Chertow, M. R., 2000. Industrial Symbiosis: Literature and Taxonomy. Annu. Rev. Energy Environ, 25:313-337 https://doi.org/10.1146/annurev.energy.25.1.313.

Chertow, M.R., 2007. “Uncovering” industrial symbiosis. J. Ind. Ecol, 11(1), 11-30. https://doi.org/10.1162/jiec.2007.1110.

Chertow, M.R., Lombardi, D.R., 2005. Quantifying economic and environmental benefits of co-located firms. Environ. Sci. Technol : 39(17), 6535-6541. https://doi.org/10.1021/es050050+.

Chertow, M., Park, J., 2016. Scholarship and practice in industrial symbiosis: 1989–2014, in: Taking Stock of Industrial Ecology. 87-116. Springer International Publishing. https://doi.org/10.1007/978-3-319-20571-7.

Chertow, M. R., Ashton, W., & Kuppalli, R., 2004. "The Industrial Symbiosis Research Symposium at Yale: Advancing the Study of Industry and Environment": *Yale School of Forestry & Environmental Studies Publications Series*. 23. https://elischolar.library.yale.edu/fes-pubs/23.

Desthieux, G., 2005. Approche systémique et participative du diagnostic urbain. Concept de représentation cognitive du système urbain en vue de l’élaboration de systèmes d’indicateurs géographiques. thèse n° 3216. EPFL, Lausanne. https://infoscience.epfl.ch/record/33684

Dong, H., Ohnishi, S., Fujita, T., Geng, Y., Fujii, M., Dong, L., 2014. Achieving carbon emission reduction through industrial & urban symbiosis: A case of Kawasaki. Energy, 64, 277-286. https://doi.org/10.1016/j.energy.2013.11.005.

Dong, L., Fujita, T., Dai, M., Geng, Y., Ren, J., Fujii, M., Wang, Y., Ohnishi, S., 2016. Towards preventative eco-industrial development: An industrial and urban symbiosis case in one typical industrial city in China. J. Clean.Prod. 114, 387-400. https://doi.org/10.1016/j.jclepro.2015.05.015.

Durand, D., 2017. La systémique: «Que sais-je?»,13ème ed, n° 1795 . Presses universitaires de France, Paris. https://www.puf.com/content/La_syst%C3%A9mique

Erkman, S., 2004. Vers une écologie industrielle, 2ème ed. Charles Léopold Mayer, Paris. https://www.eclm.fr/livre/vers-une-ecologie-industrielle/

Fang, K., Dong, L., Ren, J., Zhang, Q., Han, L., Fu, H., 2017. Carbon footprints of urban transition: Tracking circular economy promotions in Guiyang, China. Ecol. Modell. 365, 30-44. https://doi.org/10.1016/j.ecolmodel.2017.09.024.

FEDEREC., 2017. Évaluation environnementale du recyclage en France selon la méthodologie de l’analyse de cycle de vie. FEDEREC, ADEME. https://www.actu-environnement.com/media/pdf/news-28012-etude-federec-bilan-recyclage-france.pdf

Frosch, R.A., Gallopoulos, N.E., 1989. Strategies for Manufacturing. Sci. Am. 261(3), 144-153. https://doi.org/10.1038/scientificamerican0989-144.

Geng, Y., Tsuyoshi, F., Chen, X., 2010. Evaluation of innovative municipal solid waste management through urban symbiosis: A case study of Kawasaki. J. Clean. Prod. 18(10-11), 993-1000. https://doi.org/10.1016/j.jclepro.2010.03.003.

GIZ. 2014. Rapport sur la gestion des déchets solides en Algérie. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). https://www.resource-recovery.net/sites/default/files/algerie_ra_fr_web_0.pdf

GIZ. 2019. Gestion des déchets et économie circulaire [en ligne]. Deutsche Gesellschaft für Internationale Zusammenarbeit GIZ. https://www.giz.de/en/worldwide/29749.html

Hashimoto, S., Fujita, T., Geng, Y., Nagasawa, E., 2010. Realizing CO2 emission reduction through industrial symbiosis: A cement production case study for Kawasaki. Resour. Conserv. Recycl. 54(10), 704-710. https://doi.org/10.1016/j.resconrec.2009.11.013.

IEA., 2013. IEA Statistics: CO2 emissions from fuel combustion highlights. 2013 edition. International Energy Agency. https://doi.org/10.1787/co2_fuel-2013-en.

INDC., 2015. Intended Nationally Determined Contribution INDC-Algeria- (pp. 10): The People’s Democratic Republic of Algeria, First Ministry. http://climatepolicydatabase.org/index.php/Intended_Nationally_Determined_Contribution_INDC-Algeria

IPCC., 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/report/ar5/wg3/

Jacobsen, N.B., 2006. Industrial symbiosis in Kalundborg, Denmark. J. Ind. Ecol. 10(1□2), 239-255. https://doi.org/10.1162/108819806775545411.

Kaliampakos, D., Benardos, A., 2013. Underground solutions for urban waste management: status and perspectives. Report, ISWA Task Force on Globalisation and Waste Management. https://www.researchgate.net/publication/318503365_Underground_Solutions_for_Urban_Waste_Management_Status_and_Perspectives/link/596e25f04585152dd4ab5fd9/download

Kim, H.W., Dong, L., Choi, A.E.S., Fujii, M., Fujita, T., Park, H.S., 2018. Co-benefit potential of industrial and urban symbiosis using waste heat from industrial park in Ulsan, Korea. Resour. Conserv. Recycl. 135, 225-234. https://doi.org/10.1016/j.resconrec.2017.09.027.

Kurup, B., Altham, W., van Berkel, R., 2005. Triple Bottom Line Accounting Applied for Industrial Symbiosis. Aust. Life Cycle Assess. Soc. Conf.

Le Moigne, J.L., 1994. La théorie du système général: théorie de la modélisation. 2006 ed. Collection: les Classiques du Réseau Intéligence de la Complexité RIC. https://www.researchgate.net/publication/324366344_La_theorie_du_systeme_general_Theorie_de_la_modelisation

Lifset, R., & Graedel, T.E., 2002. Industrial ecology: goals and definitions. in: Ayres, R.U., Ayres, L.W. (Eds.), A handbook of industrial ecology. Edward Elgar Publishing, Inc., Massachusetts.pp.3-15. https://doi.org/10.4337/9781843765479.00009.

Lorrain, D., Chevauché, C., & Halpern, C., 2018. Villes sobres : Nouveaux modèles de gestion des ressources. Presses de Sciences Po, Paris. https://www.cairn.info/villes-sobres--9782724621907.htm

Lufkin, S., Erkman, S., & Rey, E., 2016. Strategies for symbiotic urban neighborhoods: towards local energy self-sufficiency. Springer, Cham. https://doi.org/10.1007/978-3-319-25610-8.

Massard, G., 2011. Les symbioses industrielles : une nouvelle stratégie pour l'amélioration de l'utilisation des ressources matérielles et énergétiques par les activités économiques. Université de Lausanne, Faculté des géosciences et de l'environnement. https://serval.unil.ch/fr/notice/serval:BIB_1FBA86D308CB.

Massard, G., Jacquat, O., Zürcher, D., 2014. International survey on eco-innovation parks. Learning from experiences on the spatial dimension of eco-innovation. Environ. Stud. https://doi.org/UW-1402-E

MATE., 2005. Analyse de durabilité dans le cadre du PAC « Zone côtière algéroise" (Algérie) : Rapport final. MATE, PNUE, plan bleu. http://commissariatlittoral.dz/wp-content/uploads/2018/04/Analyse-de-durabilite-PAC-Alg%C3%A9rie.pdf

McDaniels, T., Chang, S., Cole, D., Mikawoz, J., Longstaff, H., 2008. Fostering resilience to extreme events within infrastructure systems: Characterizing decision contexts for mitigation and adaptation. Glob. Environ. Chang. https://doi.org/10.1016/j.gloenvcha.2008.03.001

MEER., 2018. L'Algérie produit 34 millions de tonnes de déchets par an. [en ligne]. Ministère de l'Environnement et des Énergies Renouvelables MEER. 27 Décembre 2018. http://www.meer.gov.dz/a/?p=1648

MEER., 2019. Appel à Projet National dans les (EnR) et l'économie circulaire des déchets (ECD). [en ligne]. Ministère de l'Environnement et des Énergies Renouvelables MEER. 02Avril 2019. http://www.meer.gov.dz/a/?page_id=2657

MEFI., 2006. Les réseaux de chaleur. Ministère de l'Économie, des finances et de l'industrie MEFI. 29 mars 2006. https://www.recyclage-recuperation.fr/comptes/jcamille/reseau_chaleur.pdf

MHUV., 2011. Ministère de l'habitat, de l'Urbanisme et de la ville, Assises Nationales de l'Urbanisme : Un forum pour repenser la ville, Alger in ETTAMIR N°1- Juin 2011, Agence Nationale de l'Urbanisme ANURB, Alger. http://www.mhuv.gov.dz/Pages/Revues.aspx

Mulder, K.F., 2016. Urban symbiosis: A new paradigm in the shift towards post-carbon cities. NewDist, (July), 16-24. https://pure.tudelft.nl/portal/en/publications/urban-symbiosis(6f121ea1-a33c-4fa5-945f-f28c4bbe5011).html.

Mulder, K., 2017. Urban Symbiosis as a Strategy for Sustainabilising Cities: An Overview of Options and their Potential, Pitfalls and Solutions. Civ. Eng. Res. J. 2(3), 1-7. https://doi.org/10.19080/cerj.2017.02.555590.

Notarnicola, B., Tassielli, G., Renzulli, P.A., 2016. Industrial symbiosis in the Taranto industrial district: Current level, constraints and potential new synergies. J. Clean. Prod. 122, 133-143. https://doi.org/10.1016/j.jclepro.2016.02.056.

Ohnishi, S., Dong, H., Geng, Y., Fujii, M., Fujita, T., 2017. A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methods—Case of Kawasaki, Japan. Ecol. Indic. 73, 513-524. https://doi.org/10.1016/j.ecolind.2016.10.016.

Ouamane, K., 2017. Gestion des déchets en Algérie, enjeux et perspectives., Agence Nationale des Déchets AND. Bruxelles, 07 Mars 2017. https://agidalgerie.files.wordpress.com/2017/04/annexe-6-prc3a9sentation-and.pdf

Panayiotou, G.P., Bianchi, G., Georgiou, G., Aresti, L., Argyrou, M., Agathokleous, R., Tsamos, K.M., Tassou, S.A., Florides, G., Kalogirou, S., Christodoulides, P., 2017. Preliminary assessment of waste heat potential in major European industries, in: Energy Procedia. 123, 335-345. https://doi.org/10.1016/j.egypro.2017.07.263

PDAU., 2016. Révision du Plan Directeur d'Aménagement et d'Urbanisme de la Wilaya d'Alger: PDAU d'Alger - Rapport d'orientation. Wilaya d'Alger, PARQUEXPO.

Planète Energie. 2014. La méthanisation : du biogaz dans nos déchets. https://www.planete-energies.com/fr/medias/decryptages/la-methanisation-du-biogaz-dans-nos-dechets

PNAE-DD, 2002. Plan National d'Actions pour l'Environnement et le Développement Durable PNAE-DD. Ministère de l'Aménagement du Territoire et de l'Environnement : MATE, Janvier 2002. https://www.ecolex.org/fr/details/literature/plan-national-dactions-pour-lenvironnement-et-le-developpement-durable-pnae-dd-mon-082573/

PNC., 2019. Plan National Climat PNC. Ministère de l'Environnement et des Énergies Renouvelables : MEER, GIZ. Septembre 2019. http://www.meer.gov.dz/a/?wpdmpro=plan-national-climat

Repetti, A., 2004. Un concept de monitoring participatif au service des villes en développement. thèse n° 2903. EPFL. Lausanne. https://infoscience.epfl.ch/record/33378.

Ressources naturelles Canada. (2014). Les faits : Consommation de carburant et CO2. https://www.rncan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/fuel-efficient-technologies/autosmart_factsheet_6_f.pdf

Rey, E., 2013. Vers la ville symbiotique?. In Actes de la 7ème conférence du Forum Ecoparc," Vers la ville symbiotique? Valoriser les ressources cachées" . Cahier spécial de la revue Tracés, novembre 2013, 3-5. https://infoscience.epfl.ch/record/190579.

SDGDI 1., 2010. Étude du Schéma Directeur de la Gestion des Déchets Industriels de la Wilaya d'Alger- Diagnostic Évaluation des données de base : Rapport final Mission 1. Wilaya d'Alger, Alger.

SNAT., 2010. Loi n°10-02 du 29 juin 2010 portant approbation du Schéma National d'Aménagement du Territoire. MATE, Journal Officiel n°61, Alger, 107p. https://www.joradp.dz/ftp/jo-francais/2010/f2010061.pdf

SOFIES., 2011. Écologie industrielle à Genève : Les réseaux d'entreprises et les symbioses industrielles Rapport pour Groupe de travail Ecosite (Agenda 21). Genève : Solutions For Industrial Ecosystems (SOFIES): Office de l'environnement (OdE - DSPE). https://www.genie.ch/library/h/ecologie-industrielle-a-geneve---les-reseaux-dentreprises-et-les-symbioses-industrielles.html

SONELGAZ., 2013. *Bulletin Statistiques des sociétés énergétiques du Groupe Sonelgaz.* Société Algérienne de l'électricité et du gaz Sonelgaz.

Sterr, T., Ott, T., 2004. The industrial region as a promising unit for eco-industrial development - Reflections, practical experience and establishment of innovative instruments to support industrial ecology. J. Clean. Prod. 12(8-10), 947-965. https://doi.org/10.1016/j.jclepro.2004.02.029.

Suzuki, H., Dastur, A., Moffatt, S., Yabuki, N., Maruyama, H., 2010. Eco2 Cities: Ecological Cities as Economic Cities. The World Bank, Washington D.C. https://doi.org/10.1596/978-0-8213-8046-8.

SWEEPNET., 2010. Rapport pays sur la gestion des déchets solides en Algérie - Études de cas : Algérie. Le réseau régional d'échange d'informations et d'expertise dans le secteur des déchets dans les pays du Maghreb et du Mashreq SWEEPNET. Juillet 2010.

Thietart, R.-A., 2014. Méthodes de recherche en management, Méthodes de recherche en management. 4ème Ed. Dunod, Paris. https://doi.org/10.3917/dunod.thiet.2014.01.

Toubin, M., Lhomme, S., Diab, Y., Serre, D., Laganier, R., 2012. La Résilience urbaine: un nouveau concept opérationnel vecteur de durabilité urbaine? Développement Durable et Territoires. https://doi.org/10.4000/developpementdurable.9208

Van Berkel, R., Fujita, T., Hashimoto, S., Fujii, M., 2009a. Quantitative assessment of urban and industrial symbiosis in Kawasaki, Japan. Environ. Sci. Technol. 43(5), 1271–1281. https://doi.org/10.1021/es803319r

Van Berkel, R., Fujita, T., Hashimoto, S., Geng, Y., 2009b. Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997-2006. J. Environ. Manage. 90(3), 1544-1556. https://doi.org/10.1016/j.jenvman.2008.11.010

Vernay, A. L., 2013. Circular Urban Systems, moving towards systems integration. TU Delft. https://doi.org/10.4233/uuid:c7e37777-eb7a-4e5f-b0e3-ec93f68a655d.

Vernay, A.L., Mulder, K.F., 2016. Organising urban symbiosis projects, in: Proceedings of the Institution of Civil Engineers: Engineering Sustainability. 169 (5). 181-188 https://doi.org/10.1680/jensu.15.00010.

8. Appendices

Appendix A : *Scenario design analysis method*

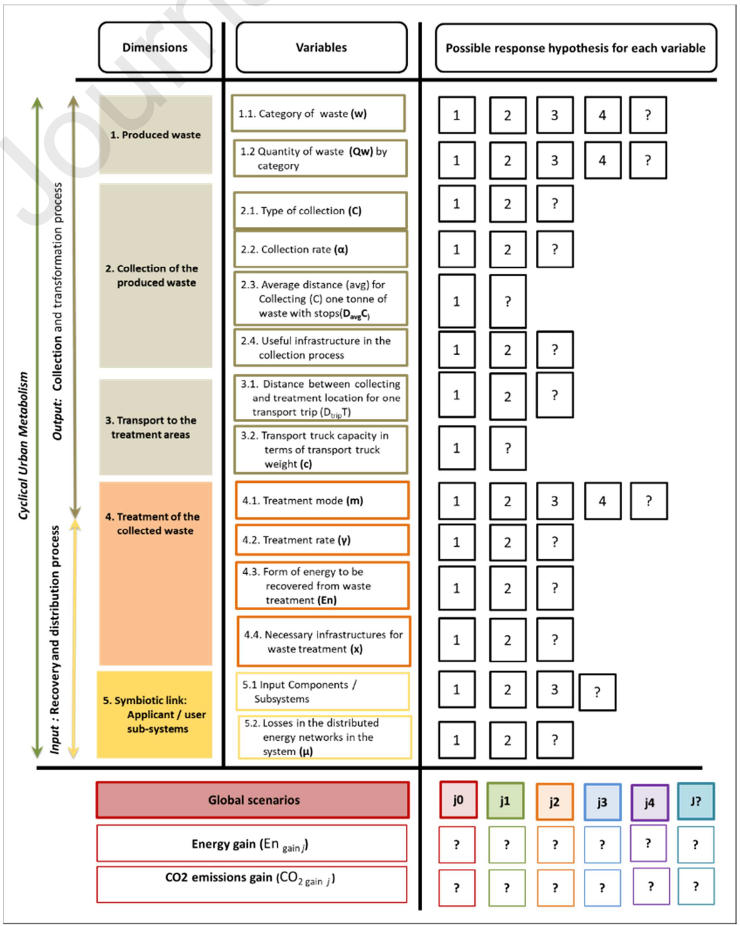

Figure A. 1: Morphological space of possible symbiotic scenarios according to a cyclical Urban Metabolism

Appendix B : *Detailed calculation formulas*

From formulas (1.1) and **(1.2)**

$$\boxed{\boldsymbol{B.1}}\begin{cases} \mathrm{D_{cons}En_j} = \left(\mathrm{elec_j} + \mathrm{gas_j}\right) \\ \mathrm{I_{mob}En_j} = En_{collection\,j} + En_{transport\,j} + En_{\mathrm{treatment}\,j} \\ En_{collection\,j} = \beta_1 * \mathrm{D_{avg}C} * \mathrm{Q_{collected}w_j} \\ En_{transport\,j} = \beta_2 * \mathrm{D_{trip}\,T} * {}^{\mathrm{n}}/_{\mathrm{C}} * \mathrm{Q_{collected}w_j} \\ En_{\mathrm{treatment}\,j} = \sum_{\mathrm{w}}(\text{Ʊ}_{(\mathrm{m,w})\mathrm{j}} * \mathrm{Q_{treated}w_j}) \\ \mathrm{Q_{collected}w_j} = \alpha_j * \mathrm{Qw_j} \\ \mathrm{Q_{treated}w_j} = \alpha_j * \gamma_j * \mathrm{Qw_{m,j}} \\ \mathrm{G_{emb}En_j} = \varepsilon * \alpha_j * \gamma_j * \sum_{\mathrm{x}} \mathrm{Qw_{x,j}} \end{cases}$$

From formulas (2.1) and **(2.2)**

$$\boxed{\boldsymbol{B.2}}\begin{cases} CO_{2(D_{cons}En)_j} = elec_j * EF_{elec} + gas_j * EF_{gas} \\ CO_{2(I_{mob}En)_j} = \left(En_{collection\,j} + En_{transport\,j}\right) * EF_{transport} + \sum_w(Q_{treated}w_{(m)j} * EF_{treatment\,(w,m)}) \\ CO_{2(G_{emb}En)_j} = G_{emb}En_j * EF_{G_{emb}\,En} \end{cases}$$

From formulas (1.3) and (1.4)

$$\boxed{\boldsymbol{B.3}}\begin{cases} \mathrm{AvEn_j} = \text{¢} * \mathrm{Q_{treated}w_j} \\ \mathrm{MiEn_j} = \sum_{\mathrm{w}}(\text{ƫ}\mathrm{M} * \mathrm{Q_{recycled}w_j}) \\ \mathrm{PrEn_j} = \sum_{\mathrm{w}}(\text{þ}_{(\mathrm{m,w})} * \mathrm{Q_{treated}w_j}) \\ \mathrm{FaEn_j} = \upsilon * \sum_w(\text{Ʊ}_w * \mathrm{Q_{treated}w_j}) \\ \mathrm{LoEn_j} = \left(\mathrm{PrEn_j} + \mathrm{FaEn_j}\right) * \mu \end{cases}$$

From formulas (2.3) and (2.4)

$$\boxed{\boldsymbol{B.4}}\begin{cases} \mathrm{AvCO_{2(AvEn)j}} = \text{ȼ} * \mathrm{Q_{treated}w_j} \\ \mathrm{AvCO_{2(MiEn)j}} = \sum_{\mathrm{w}}(\text{ɘ}_w * \mathrm{Q_{recycled}w_j}) \\ \mathrm{AvCO_{2(PrEn)j}} = \sum_{\mathrm{w}}(\text{Ə}_{(\mathrm{m,w})} * \mathrm{Q_{treated}w_j}) \\ \mathrm{AvCO_{2(FaEn)j}} = \mathrm{FaEn_j} * \mathrm{EF_{elec}} \\ \mathrm{AvCO_{2(LoEn)j}} = (\mathrm{AvCO_{2\,(PrEn)j}} + \mathrm{AvCO_{2(FaEn)j}}) * \rho \end{cases}$$

Appendix C : *Detailed results*

	Indicators	Abbreviation	Unit	j0	j1	j2	j3	j4	j5
A	**Used fossil Energy under scenario *j*** ($U_f\,En_j$)								
A.1	**Direct consumed Energy under scenario *j* (DconsEn j)**								
	Electricity	$elec_j$	GWh/y	267,425	267,425	267,425	267,425	267,425	267,425
	Natural gas	gas_j	1000000 th/y	497,132	497,132	497,132	497,132	497,132	497,132
		gas_j	GWh/y	578,165	578,165	578,165	578,165	578,165	578,165
Total Direct consumed Energy		**$D_{cons}En_j$**	**GWh/y**	**845,59**	**845,59**	**845,59**	**845,59**	**845,59**	**845,59**
A.2.	**Indirect mobilized Energy for waste treatment under scenario *j* (ImobEn j)**								
	Energy for Collection	$En_{collection\,j}$	m3/y	211,048	135,009	248,292	4,145	109,021	248,292
			GWh/y	2,267	1,450	2,667	0,045	1,171	2,667
	Energy for Transport	$En_{transport\,j}$	m3/y	41,81	-	-	-	-	-
			GWh/y	0,45	-	-	-	-	-
	Energy for Treatment	$En_{treatment\,j}$	GWh/y	2,02	0,60	2,85	0,05	22,85	23,50
Total Indirect mobilized Energy		**$I_{mob}En_j$**	**GWh/y**	**4,74**	**2,05**	**5,52**	**0,09**	**24,02**	**26,16**
A.3	**Gray embodied Energy in the processes of implementing treatment facilities, under scenario *j*** ($G_{emb}En_j$)								
	Waste collection center	x_1	GWh/y	-	1,18	1,18	1,18	1,18	1,18
	Methanization plant	x_2	GWh/y	-	0,64	-	-	-	0,64
	Textile industry	x_3	GWh/y	-	-	-	-	0,15	0,15
	Heat networks	x_4	GWh/y	-	-	-	-	0,52	0,52
Total Gray embodied Energy		**$G_{emb}En_j$**	**GWh/y**	-	**1,83**	**1,18**	**1,18**	**1,85**	**2,49**
Total Used fossil Energy		**$U_f\,En_j$**	**GWh/an**	**850,3**	**849,5**	**852,3**	**846,9**	**871,5**	**874,2**
B.	**Recovered Energy from valorized waste under scenario *j*** (R_wEn_j)								
B.1	**Avoided Energy for consumption**	$AvEn_j$	GWh/y	-	3,33	6,13	0,10	2,69	6,13
B.2	**Reduced Energy**	$MiEn_j$	GWh/y	-	-	-	-	264,48	264,48
B.3	**Produced Energy**	$PrEn_j$	GWh/y	-	9,98	44,38	1,33	-	11,32
B.4	**Recovered Fatal Energy**	$FaEn_j$	GWh/y	-	-	-	-	2,74	2,74
B.5	**Lost Energy**	$LoEn_j$	GWh/y	-	1,00	4,44	0,13	0,27	1,41
Total Recovered Energy		**R_wEn_j**	**GWh/y**	-	**12,32**	**46,07**	**1,30**	**269,64**	**283,26**
Total Optimized Energy per scenario		$OpEn_j$	**GWh/y**	**850,3**	**837,2**	**806,2**	**845,6**	**601,8**	**591,0**
Total Energy Gains compared to Scenario "j0"		$En_{Gain\,j}$	**GWh/y**	**-**	**13,18**	**44,10**	**4,77**	**248,5**	**259,3**
			%	**0%**	**1,55%**	**5,19%**	**0,56%**	**29,2%**	**30,5%**
Reference values	National objective		**%**	**7%**					
	Corresponding targeted gain		**GWh/y**	**59,52**					
	Corresponding targeted Energy optimization		**GWh/y**	**790,807**					

Table C. 1: Comparative quantification results of the optimized energy potential and associated gains for all scenarios

	Indicators	Abbreviation	Unit	j0	j1	j2	j3	j4	j5
A	**Generated CO_2 Emissions from Used fossil Energy, under scenario *j* (GeEm $_{(U.f.En)\ j}$)**								
A.1	**CO_2 Emissions from Direct consumed Energy, under scenario *j* ($CO_{2\ (DconsEn)\ j}$)**								
	a. CO_2 from electricity	CO_2 elec $_j$	$ktCO_2e/y$	146,55	146,55	146,55	146,55	146,55	146,55
	b. CO_2 from natural gas	CO_2 gas $_j$	$ktCO_2e/y$	131,24	131,24	131,24	131,24	131,24	131,24
Total CO_2 from Used fossil Energy		**GeEm $_{(U.f.En)\ j}$**	**$ktCO_2e/y$**	**277,8**	**277,8**	**277,8**	**277,8**	**277,8**	**277,8**
A.2	**CO_2 Emissions from Indirect mobilized Energy, under scenario *j* ($CO_{2\ (ImobEn)\ j}$)**								
	CO_2 from Collection	$CO_{2\ collection\ j}$	$ktCO_2e/y$	0,561	0,359	0,660	0,011	0,290	0,660
	CO_2 from Transport	$CO_{2\ transport\ j}$	$ktCO_2e/y$	0,11	-	-	-	-	-
	CO_2 from Treatment	$CO_{2\ treatment\ j}$	$ktCO_2e/y$	0,50	0,14	0,65	0,01	3,77	3,91
Total CO_2 from Indirect mobilized Energy		$CO_{2\ (ImobEn)\ j}$	**$ktCO_2e/y$**	**1,17**	**0,50**	**1,31**	**0,02**	**4,06**	**4,58**
A.3	**CO_2 Emissions from Gray embodied Energy, under scenario *j* ($CO_{2\ (GembEn)\ j}$)**								
Total CO_2 from Gray embodied Energy		**$CO_{2\ (GembEn)\ j}$**	**ktCO2e/y**	**-**	**1,00**	**0,65**	**0,65**	**1,01**	**1,37**
Total CO_2 from Used fossil Energy		**GeEm $_{(U.f\ .\ En)\ j}$**	**$ktCO_2e/y$**	**278,97**	**279,29**	**279,75**	**278,46**	**282,86**	**283,73**
B.	**Avoided CO_2 Emissions by Recovering Energy from valorized waste (AvEm $_{(R.w.\ En)\ j}$)**								
B.1	**Avoided CO_2 from Avoided Energy**	$AvCO_{2(AvEn)}$	$ktCO_2e/y$	-	0,83	1,52	0,03	0,67	1,52
B.2	**Avoided CO_2 from Reduced Energy**	$AvCO_{2\ (MiEn)\ j}$	$ktCO_2e/y$	-	-	-	-	38,13	38,13
B.3	**Avoided CO_2 from Produced Energy**	$AvCO_{2\ (PrEn)\ j}$	$ktCO_2e/y$	-	0,86	10,81	0,32	-	1,19
B.4	**Avoided CO_2 from Recovered Fatal Energy**	$AvCO_{2\ (FaEn)}$	$ktCO_2e/y$	-	-	-	-	1,50	1,50
B.5	**Avoided CO_2 from Lost Energy**	$AvCO_{2(LoEn)\ j}$	$ktCO_2e/y$	-	0,09	1,08	0,03	0,15	0,27
Total Avoided CO_2 Emissions		AvEm $_{(R.w.\ En)\ j}$	$ktCO_2e/y$	-	**1,60**	**11,25**	**0,32**	**40,14**	**42,06**
Total Reduced CO_2 Emissions per scenario		**ReEm $_j$**	**$ktCO_2e/y$**	**278,97**	**277,77**	**269,58**	**278,18**	**242,87**	**241,94**
Total CO_2 Emissions gain compared to scenario "j0"		**$CO_{2\ Gain\ i}$**	**$ktCO_2e/y$**	**-**	**1,19**	**9,39**	**0,79**	**36,10**	**37,02**
			%	**0%**	**0,43%**	**3,36%**	**0,28%**	**12,94%**	**13,27%**
Reference values	National objective		**%**	**7%**					
	Corresponding targeted gain		**$ktCO_2e/y$**	**19,53**					
	Corresponding targeted CO_2 reduction		**$ktCO_2e/y$**	**259,439**					

Table C. 2: Comparative quantification results of the CO2 emission reduction potential and associated gains for each scenario

9. Notes

[1] 767 referencing document.

[2] Algiers has 57 municipalities grouped into13 administrative districts (Daïras). El Harrach daïra comprises four municipalities, including El Harrach (Daira capital), Oued Smar, Bachdjerrah, and Bourouba. However, in the meaning of spatial-functional management and urban planning, the inter-municipality organization is not defined under the Algerian legislation.

[3] The diagnosis conducted as part of this study related to the 57 municipalities of Algiers, it aimed to assess the balance of UM through identifying, on the one hand, both, the most active municipalities, in terms of local urban development and those characterized by a linear UM, in terms of natural resources consumption and the generated pollution related to waste emissions. On the other hand, it identifies the means established for optimization. Based on an internal bench-marking method (comparison with the average values of all Algiers municipalities), the assessment was divided into 08 criteria, 16 measurement parameters, and 30 indicators, for each of Algiers' 57 municipalities. The results demonstrated the urban metabolism imbalance in Algiers and highlighted the ElH-OS's local intercommunal territory's metabolic problems. With high energy consumption, the production of large quantities of waste, and the pollution of Oued El Harrach from urban and industrial wastes, as well as the failure in UM planning and management.

[4] Since then, this data has not been updated by the concerned institutions, pending an upcoming general economic census and the 2020 national population and housing census, which should include environmental information in the statistical questionnaire.

[5] *"ALFEL"* Algerian Foundry Company, whose production based on metal scrap transformation, "ALFEL" receives and melts about 4,000 tons of ferrous metals per year for a finished product manufacturing of about 3,200 tons . The scrap received comes from various sources. It should be noted that ALFEL is not a waste treatment company and is not declared in this activity (SDDI, 2010). "ECFERAL," a Boiler making and Tinsmithing Company specialized in metal boiler vats manufacturing. It also developed other activities such as incineration and the manufacturing of small incinerators. Those are particularly suitable for expired medicines and waste from infectious-risk medical care activities. "ECFERAL" has an incineration plant that treats about 1.5 tons of waste per day (SDGDI, 2010).

[6] Pillar 1 covers, a.o., projects relating to the development of industrial and commercial activities as well as the energy network; Pillar 3 covers residential projects, transport infrastructures, socio-cultural and leisure projects; Pillar 5 covers, a.o., projects relating to the preservation and enhancement of natural heritage (forests, natural and urban parks, others), the development of urban agricultural parks, as well as the waste treatment projects (collection, sorting, recycling, disposal) and wastewater recovery and treatment ones.

Highlights

- UrS could be useful to realize global strategic climatic goals at the local scale
- It offers more opportunities to loop flows between various activities than IS
- Algiers' local case study proves its efficiency to reduce energy use & CO2 emissions
- UrS should be incorporated into Algerian urban planning and energy management tools
- Setting up an UrS would require an evolution of the local urban development policy

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: