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Algerian Coastal and Marine Ecological Footprint Assessment:

Feasibility and Constraints

Defender

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Dedicated to

The making of this work couldn't be achieved without Allah's mercy and blessing

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ACRONYMS

AADL	:	National Housing Improvement and Development Agency (Agence nationale d'amélioration et du développement du logement)
AND	:	National waste agency (Agence nationale des déchets)
BAT	:	Best available techniques
BC	:	Biocapacity
BNEDER	:	National Office of Studies for Rural Development (Bureau national des études pour le development rural)
DEP	:	Directory of public equipment (Direction des équipements publics)
DGF	:	General Directorate of Forestry (Direction générale des forêts)
DL	:	Housing directory (Direction du logement)
DPRH	:	Fishing and fishery resources directory (Direction de la pêche et de la production halieutique)
DPSB	:	Programming and budget monitoring directory (Direction de la programmation et du Suivi Budgétaires)
DSASI	:	Directorate of statistics and agricultural information systems (Direction de la statistique et des systèmes d'information agricoles)
DTP	:	Public work directory (Direction des travaux publics)
DUAC	:	Directorate of Architecture and Urbanism (Direction de l'urbanisme, de l'architecture et de la construction)
EF	:	Ecological footprint
EGPP	:	Management company of fishing harbours and fishing (shelters Entreprise de gestion des ports et des abris de pêche)
EMC	:	Environmentally-weighted Material Consumption
EF_Built	:	Ecological footprint of built area
EF_c	:	Ecological footprint of carbon emissions
EF_emb	:	Ecological footprint of embodied energy
EF_opt	:	Ecological footprint of operational energy
EQF	:	Equivalence factor
FAO	:	United Nations' food and agriculture organization
GEMIS	:	Global emission model for integrated systems
GFN	:	Global footprint network
Gha	:	Global hectares
GHG	:	Greenhouse gases
GJ	:	Giga Joule
HANPP	:	Human appropriation of net primary production
HDEP	:	High-Density polyethylene
IEA	:	International Energy Agency
LCA	:	Life cycle assessement
LPA	:	Assisted Promotional Housing (Logement Promotionnel Aidé)
LPP	:	Public Promotional Housing (Logement Public Promotionnel)
LEAC	:	Land and Ecosystem Accounting
MADR	:	Ministry of agriculture and rural development (Ministère de l'agriculture et du développement rural)

MHUV	:	Ministry of housing and urban planning (Ministère de l'habitat, de l'urbanisme et de la ville)
MPRH	:	Ministry of fishing and fishery Production (Ministère de la pêche et de la production halieutique)
MSW	:	Municipal solid waste
Mt CO_2eq	:	Mectric tonne of carbon dioxid
Nha	:	National hectares
NFA	:	National footprint account
PET	:	Polyethylene terephthalate
SEAAL	:	Water and sanitation company of Algiers (Société des Eaux et de l'Assainissement d'Alger)
SONELGAZ	:	Algerian energy industrial group for production, distribution and marketing of electricity (Groupe industriel algérien de la production, la distribution et la commercialisation d'électricité et de gaz naturel)
TEEB	:	The economy of ecosystems and biodiversity
TL	:	Trophic level
UMA	:	Urban metabolisme analysis
UW	:	Urban wastewater
YF	:	Yield factor
ZET	:	Zone of touristic expansion (Zone d'expansion touristique)

INTRODUCTION

Current studies provide insights to comprehensively define the planetary boundaries not to be exceeded to avoid potential disasters in response to any transgression. A typical example is the carbon dioxide levels in the atmosphere (Rockström et al., 2009; Rockström, 2015). However, these boundaries are constantly being adjusted through decisions, strategies, policies, and other action programs by experts to maintain human activity within the acceptable operating zone (Lewis, 2012). These measures are necessary due to the rapid growth and the spatial expansion of the human population combined with the intense development of its activities and the resulting pollution. Many studies show that human use has reached the critical limit of some planetary components, including biodiversity (Meadows et al., 1972; Rockström et al., 2009), which could be due to the difficulty of defining the critical limit accurately.

Furthermore, assessing and managing the human-environment system is challenging (Lenton et al., 2007; Lewis, 2012; Running, 2012). The definition of planetary boundaries has frequently relied on quantitative measures and simple logic that compare human needs, material supply, and potential tipping points that should not be crossed (Lewis, 2012). Indeed, the planetary boundaries framework links different concepts and models for assessing natural resource status, its use, and human impact on the environment. These concepts mainly involve policy targets such as the Sustainable Development Goals, life cycle analysis-based studies to quantify environmental impacts, and consumption-based indicators such as terrestrial primary production (plant), ecosystem capacity (carrying capacity) or ecosystem area and productivity such as footprinting (Running, 2012; Dao, 2015; Dao et al., 2018; Sala et al., 2020).

The emergence of sustainable development indicators has accompanied the widespread popularization and acceptance of this concept by many countries, fuelled by the need for action declared at the Rio Earth Summit in 1992, especially after the Agenda 21 was produced (UNCED, 1992). These indicators describe an accounting system or a complex of indexes to assess and report environmental and social conditions (Fiksel et al., 2012).

In light of the risks to global ecosystems and societies, several emerging indicators focus on describing the loss of natural habitats, biodiversity, resources, and resilience (EU, 2021). Among these are those that describe the ecological balance by comparing a country or community's natural capital assets, which include all resources consumed and used by populations, to the country's natural capital. This ecological accounting, which is inspired by economic models (Pearce et al., 1998), is expressed in terms of green national income (net national income) or ecological footprint (gross national product) to assess the environmental performance of a country, region, or system (Atkinson & Dietz, 2019). In addition, Diallo (2021) argues that incorporating natural capital into the country's socioeconomic asset accounting enables the estimate of ecosystem service losses, costs associated with these losses, and expenses that may arise from the restoration of degraded ecosystems and their associated services. Natural capital is thus a key component of indicators that measure the performance of countries in their green growth transition, which consists of improving the living conditions of populations while maintaining the integrity of natural ecosystems (Knight-Lenihan, 2019;

Acosta et al., 2020). it is the global case that the world's population, which is in a state of accelerating loss of forest, aquatic, and marine ecosystems at all scales (World Resources Institute, 2000; Gibbs et al., 2010; Mauchamp et al., 2012; Shaffer et al., 2019; Attenborough; 2020; Augustine et al., 2021; WWF, 2022). Indeed, marine environments are not exempted from anthropogenic impacts, particularly fish stocks, which are overexploited. Overfishing of high commercial value species puts the Mediterranean fisheries second after the South Pacific in terms of an unsustainable catch of the stock, with a percentage of 63.4% (FAO, 2022). Mediterranean regions are already vulnerable due to the increase in water temperature and the introduction of non-indigenous species that can have a substantial impact on the development and food security of the coastal populations, particularly in the South and South-East fisheries of developing countries (UNEP/EEA, 1999; Molnar et al., 2008; FAO, 2019; FAO, 2020; Stergiou et al., 2016; EEA, 2022; Zenetos et al., 2022). Furthermore, southern Mediterranean countries are in dire straits due to human expansion and related activities (industry, agriculture, aquaculture), whose ecological consequences include the loss of forest areas and natural habitats, the degradation of water quality due to the increase of sediments, and the eutrophication of coastal waters (UNEP/MAP, 2015; Akubia, 2016; Gianni, 2016).

Algeria is similar as its coastline, which represents only 4% of the national territory, hosts about two-thirds of the population (Meghfour Kacemi & Tabet Aoul, 2007; Kacemi, 2008; 2011; Bouroumi, 2018; Rabehi et al., 2019). As a matter of fact, the urbanization trend's studies describe the percentage of the urban population in Algeria as comparable to that of European countries at over 70% (Reiffers et al., 2014; MAE, 2019; UNDSA, 2020). The latter is a result of population migration to large urban cities such as Algiers, Oran, and Constantine due to the convergence of permanent activities such as civil service, commerce, and industry (Kacemi, 2011; Reiffers et al., 2014) and seasonal activities such as coastal tourism (Lakhal, 2018; Meghfour Kacemi &Tabet Aoul, 2007).

The increasing demand for space encourages the implementation and construction of dwellings that are still considered below the need, thus inducing unplanned construction since the 70s (CAHF, 2021). Consequently, since 2014, the Algerian governmental authorities have attempted to overcome this issue by developing several housing programs and the creation of new cities (Hassi Messaoud, Sidi Abdellah, El Ménéaa, Boughezoul, Bouinan) with a total area of urbanization of more than 9 000 hectares to meet the demand and decrease the pressure on specific urban centers such as Algiers (CAHF., 2021; NUA., 2021; MHUV., 2022). These efforts are also supported by improved access to essential public services (electricity, gas, water, sanitation, and telecommunications) at a rate of 100% for water supply in urban areas, 91% for sanitation, 99% for electricity (3355 households), 65% for natural gas (11565 households), and fuel products (2986 households) (CDER, 2015; NUA, 2021; MHUV, 2022).

However, considering its international engagements, the country is held to attribute more attention and integrate the environmental component into its development projects. Indeed, Algeria counts an important range of international, regional, and national ratified conventions for protecting the environment. Moreover, the Paris agreement, the United Nations Framework Convention on Climate Change ratified in 1993 (UNFCCC), and the Kyoto Protocol requires the country to focus on greenhouse gas emissions, primarily CO_2 resulting from the building sector, hydrocarbons (refining) and transport (Hamida, 2011; Berghout, 2022), as, based on its emissions, Algeria ranks 152nd worldwide and 3rd in Africa (Bouznit & Pablo-Romero, 2016; Ritchie et al., 2020). The national authorities' concerns include other components, namely biodiversity, natural ecosystems, and pollution, for which the country has also adopted multiple tools, such as the Biodiversity Convention. In the same perspective, Algeria's international engagement has led to the establishment of legal texts at the national level (EEA/MAT/ONDD, 2012; UNDP, 2018; PNEU/PAM/SPA/RAC, 2018; ANEP, 2022).

Algeria is thus facing the challenges of sustainable development, primarily because of its modest economic growth, which further complicates access to the knowledge, skills, and technologies needed to meet the requirements of such development (Djeflat, 2010; Bouyacoub, 2012a, b). Added to this first complication is the pressure of the country's growing population, associated with a high demand for resources, services (health, transportation, employment), and space (Koné, 2014; Boumaza, 2015; Esgalhado et al., 2021). Therefore, these demands should be held in cities that must be conceived to evolve and meet the standards of sustainable development, namely efficient economic growth, resource sustainability, and the well-being of its residents (Djoufelkit, 2008; UN, 2014; Petruzzella & Sancassani, 2017; Tsaki, 2018). Accordingly, Algeria's development strategies require the implementation of accounting systems integrating socioeconomic and environmental parameters to investigate the country's assets and resources, their exploitation rate, and the possible risks associated with the loss of these resources.

This thesis assesses the use of materials, energy, and surfaces in the different sectors of activity, including fishing, agriculture and animal husbandry, forestry, urbanization, water consumption, and urban waste management, in coastal wilayas, which are the main urban centers of anthropic activity. Hence, this work aims at exploring the sustainability of the two coastal cities (wilayas) of Algiers and Tipaza based on the ecological footprint analysis EF. Broadly, the EF measures human activity's dependence on the environment in terms of the area required for producing goods and resources and the abatement of the related impacts (Wackernagel & Rees, 1996). This analysis is built on local statistics to comprehensively describe the investigated environment. Nevertheless, this work was performed in the context of data scarcity and required additional analysis, such as the urban metabolism analysis and life cycle assessment.

Beyond providing an analysis of the natural resource' status in Algeria, this study contributes to the limited literature on EF and life cycle assessment in Algeria. Indeed, the method described presents a detailed inventory of energy use, carbon dioxide emissions, and land use associated with each activity sector. In line with the cross-city learning perspective, this work also aims to provide sufficiently reliable data to allow comparability of Algerian coastal cities with other cities in different contexts, such as Mediterranean cities. Most importantly, the purpose is to present the EF as an effective tool that could contribute to the development of resource management policies, especially at the local level, since the original vision of the EF founders was to provide a management and planning tool (Rees, 1992; Rees & Wackernagel, 1996), and as a communication and educational tool to raise consumer awareness. In this regard the two key sections of this manuscript are as follows.

An analysis of the EF and a discussion of the constraints encountered during the application of this model to the Algerian coastal city. The content is structured into five chapters.

The first chapter deals with the theoretical aspect of this project. The latter, introduces and describes the study context and the basis of the EF and related concepts. The second chapter presents the study area, namely the wilaya of Algiers and the wilaya of Tipaza. This presentation follows the EF model's structure, expressing the supply and demand of resources. Indeed, the EF compares the demand for a given resource in terms of a hypothetical required productive area to the existing area called "Biocapacity BC." Accordingly, this chapter describes the economic and environmental assets of each wilaya (e.g., fisheries production, forest) and its current socio-economic activities.

Chapter three describes the thesis's principal workload. The methodological approach is described in detail in this chapter. It includes both a data collection and a data assessment system. It also defines the assumptions employed in the computations supported by further explanations in the appendices. This chapter is followed by a presentation of the study findings and a detailed discussion of each result. The second section outlines, in chapter five, the main constraints related to both the EF model and its application at the wilaya level. Finally, the main and concluding assertions are stated in the conclusion, which answers central questions regarding this study: does the EF apply to the Algerian coastal wilayas? How much bioproductive land do these wilayas' economic activities actually require?

CHAPTER 01. The state of the art of the Ecological Footprint indicator

1.1. Study context

Cities are considered dissipative structures governed by thermodynamic principles for energy and material transfer, resulting in a permanent imbalance (Rees, 2011, 2012; Bettignies et al., 2019; Gallopín, 2020) and greatly depending on their hinterland (Lenzen & Peters, 2010; Lenzen et al., 2014; Gallopín, 2020), implying that the pressure of these structures exceeds their boundaries (Folke et al., 1997). Indeed, the environment surrounding cities are under continuous and increasing pressure, as cities expansion is fuel by its growing population, as more than 60% of the world's population is expected to be living in cities around 2030 (IISG, 2016). These urban centers represent the breeding grounds for the economy but are also a source of several forms of pollution, such as carbon dioxide emissions of more than 70% (Shimomura & Tadashi, 2010; Wade, 2014; UNEP, 2017; Bettignies et al., 2019; Palme & Salvati, 2019; Enel group, 2020; Küfeoğlu, 2022). Therefore, especially in developed countries, the increasing generation of such a pollutant is likely to challenge decision-makers to find appropriate solutions, whether implementing urban forest planting operations or exploring the potential of other natural systems such as marine, river, and wetland ecosystems (Bazaz et al., 2018). In contrast, urban development in developing and less developed countries raises numerous concerns. Mainly the increased sprawl of the population accompanied by undesirable events of resource depletion, inequality, and weather conditions, therby putting additional strain on resource management policies (Henderson, 2002; El Sakka & El khamess, 2015; Padraig, 2016; Raed & Mounjur, 2017; World Economic Forum, 2018; Abubakar & Adedoyin Aina, 2019). However, Galaeser et al. (2020) argue that urbanization in developing cities may strengthen economic productivity. Nevertheless, it will require brilliant expertise supported by accurate planning policy capacities. Developing countries must use the concepts of sustainable development to grasp the factors hindering their progress. Such analysis must be built on scientific data, allowing quantification indicators and robust measurement methods to assist with management programs (Plag et al., 2019; El Rifai, 2021). In this regard, Algeria's economic progress inspired the adoption of a set of development indicators to ensure political and economic updates and competiveness with other countries (Mesbahi, 2021). According to Algeria's human development index, the country has progressed from medium to high development over twenty years (UNDP, 2020). This index establishes an outlook based on a country's health, knowledge, and standard of living performance.

However, the improvement in quality of life is not without consequences. Thus, in its developing stage, Algeria should implement conservation measures for natural resources and the environment and increase its resilience, especially in vulnerable regions. Considerations should also include the increase in the population and the associated needs. Accordingly, Algeria has been developing numerous territorial and sectorial action plans targeting natural resource conservation, such as water (installation of desalination plant), improving the quality of transport, especially in the agglomerations (Algiers metro), reducing pollution forms (solid waste wastewater treatment), and more importantly, restructuring urbanization (United

Nations Conference on Housing and Sustainable Urban Development, 2014). Indeed, Algeria's northern area has been suffering from the increasing infrastructure development in Algeria, raising the urban population to 70.7% of the total population in 2015 (Achour-Tani, 2013; Tsaki, 2018).

On the other hand, the population's exodus has been encouraged by the diversification of socioeconomic activities and improved living conditions, especially in the country's major urban centers in the West and East, resulting in litoralization (Khaoua et al., 2014; Ghodbani & Boughrira, 2019). Indeed, coastal settlement is associated with the continuous natural habitat loss and drain on natural resources (Khaoua et al., 2014), including water, which is the basis of human activities such as agriculture, which accounts for 65% of all water use (Chabane, 2012). This resource has experienced a significant scarcity, intensified by the climate change effect (prolonged periods of drought) (GCF/Algeria, 2017). Eventually, similar to Mediterranean countries, Algeria could pay dire consequences for climate change, including coastline erosion, agricultural land, and tourism facilities loss, compromising the country's economy and food security (Petruzella & Sancassani, 2017). Thus, awareness and assessment of potential risks of degradation of natural capital could provide relevant assistance to Algerian decision-makers in developing and implementing appropriate management plans. Hence, shifting the country's development process must be supported by tools to measure all the country's assets to guide production, management, consumption, and conservation policies.

1.2. Concept, tool, Indicator, measure, analysis,

In this thesis document we will refer to the EF under several terms according to its description usages or position in the thesis document. For instance, we would refer to the EF as a “concept” when introducing the EF, describing its history and foundation and to conclude on its application in the study context. The term “tool” is also used to introduce, describe and provide opinion on the EF. For example, some authors would describe the EF as an effective urban planning tool. In this context the EF is viewed as an instrument to build planning policies.

The use of the term “indicator” is more delicate especially at the beginning of the document as in the first section we have yet to assess the EF accuracy. However, we use the term “indicator” when citing literature work, describing the attribute given to the EF. For instance, some non-governmental organizations consider the EF as a sustainable development indicator. While other experts, see it as a resources state indicators. The EF is also described a “metric” or a “measure” as it provides by the mean of mathematical calculation a result of human demand on resources. Finally, when describing the methodological approach, we use the term model or analysis. These terms as also used when applying the EF to our case study.

1.3. The model: The ecological footprint

1.3.1. Conception and use

1.3.1.1. Hypothesis

The EF follows economic welfare principles (availability of resources for humans) and ecological principles (natural resource conservation), resulting in a sustainable development indicator (Uhde, 2009). The conception of the ecological footprint was based on the assumptions in figure 1 (Weckernagle, 2002; Wernert, 2007; Uhde, 2009).

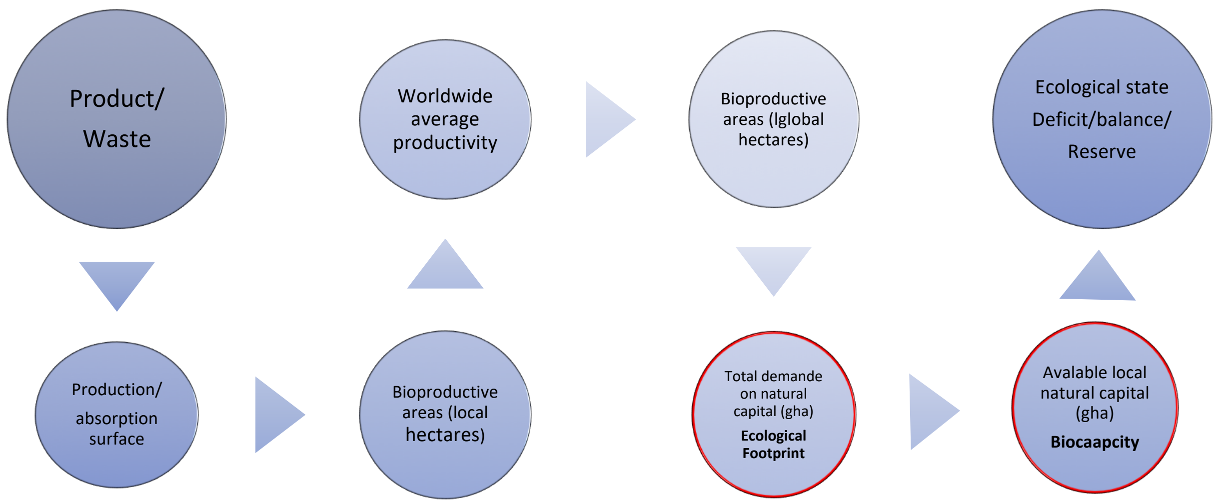

Figure 1. Ecological footprint founding assumptions

The basis of the EF is the possibility to track the annual amounts of resources consumed and waste generated per country. Logically, these resource flows are associated with resource regeneration and waste absorption lands, known as the "bioproductive area." Thus, by weighting each area according to its annual average yield of potential valuable biomass, the different areas can be measured in a standard unit known as the global hectare.

The global demand can be aggregated by summing the total area required for resource production or waste assimilation, representing the human demand for nature (EF). Then, this demand can be compared to the biological capacity or the biological supply (BC) to assess the ecological. If the demand (EF) exceeds the biocapacity (BC), this excess is called an "ecological deficit."

1.3.1.2. Definition

«The ecological footprint measures the required biologically productive land and aquatic area to produce all the resources needed by a population and absorb the waste it generates, considering current technologies and resource management practices» (Wackernagel & Rees, 1998 ; Monfreda et al., 2004; Ewing et al., 2009, 2010). Built on the global natural capital conservation principal, the EF rationale assumes that a region, a nation, an individual, or an activity sector is sustainable in its resource's use only if its annual demand on this natural

capital does not exceed its regenerative capacity (Wernert, 2007). Accordingly, the EF could be used to define resources exploitation thresholds, as it aligns perfectly with the sustainability and planetary boundaries principals, which define the tipping points beyond which irreversible change would occur (Borucke et al., 2013; Rockström, 2015; Attenborough, 2020).

1.3.1.3. Applications

The EF concept has been developed two decades ago, initially by Rees (1992) then Rees and Wackernagel (Rees & Wackernagel, 1996; Wackernagel & Rees, 1998), aiming to measure human lifestyle sustainability and its direct and indirect reliance on nature's capacity to regenerate the resources (Wackernagel & Rees, 1996; EEA., 2016; GFN, 2022a). Collaborating with the United Nations, which gathers and produces worldwide data sets, the global EF network has built a large-scale, all-use accounting system for all countries known as National Footprint Accounts (NFAs) enabling cross-country comparability (Ewing et al., 2009, 2010). The EF has raised questions since its foundation, mainly because of its structure and intriguing results. Thus, this tool has been popularized by several users at various scales (regional, local and individual), following various methods and in different contexts (collaboration, analysis, criticism, improvement of calculations). The following table lists some of the use cases of the EF (**table 1**).

Table 1. Applications of the ecological footprint concept

Context	Framework	Title	Country	Author	Year
Baseline	National Footprint Account Guidebook	Working Guidebook to the National Footprint Accounts: 2016	International	Lin et al.	2016
State of the resource	Collaboration	Mediterranean Ecological Footprint Initiative	Regional (Mediterra-nean countries)	GFN et Fondation Mava	2015
		State of the States: A New Perspective on the Wealth of Our Nation,”	United States	Kelly et al.	2015
		Ecological Footprint of Mediterranean coastal cities: Awareness creation and policy implications	Regional (Mediterra-nean countries)	Babou et al.	2017
Managem ent policies of resources	Article	Conflicts and ecological footprint in MENA countries: implications for sustainable terrestrial ecosystem	Regional (Mediterra-nean countries)	Usmane et al.	2021
Methodolo gical approach	Comparison	Ecological Footprint Time Series of Austria, the Philippines, and South Korea for 1961-1999: Comparing the Conventional Approach to an “Actual Land demand” Approach.	Austria	Wackernag el et al.	2004
National account-	National report	An Ecological Footprint Study of New South Wales and Sydney	Wales	Lenzen	2006

ting of the EF					
Adoption of an environ-mental indicator	National initiative	Japan's government adopts EF in the country's basic environmental plan since 2006	Japan	GFN et le Japon	2000-2020
		Al Basma Al Beeiya	Unites Arab Emirates (UAE)	GFN	2007
Re-newable energy and carbon	Article	The Carbon Footprint Model as a plea for Cities towards Energy-Transition: The case of Algiers-Algeria	Algeria	Hachaichi	2019
Cities' EF		The ecological footprint of Algerian cities: Djelfa, M'sila and Laghouat.	Algeria (Incomplete)	Zeggar	-
		Urban eco-institutional footprint: a decision support tool for the evaluation and control of urban metabolism in Algeria	Algeria (Incomplete)	Dakhia	2015
		The study of sustainable development in the coastal city agglomeration of Shandong province based on the energy-ecological footprint	China	Yang	2011
Tourism sustaina-bility	Article	Exploring the ecological footprint of tourism in Ontario	Canada	Johnson	2003
		Sustainable Tourism: Whale Watching Footprint in the Bahia de Banderas, Mexico	Mexico	Cornejo Ortega et al.	2013
Fishing and aqua-farming		The Ecological Fishprint of Nations. Measuring Humanity's Impact on Marine Ecosystems	Global	Talberth et al.	2006
		The Ecological Footprint Concept for Sustainable Seafood Production: A Review	Global	Folke et al.	1998
Individual EF	Software	Ecological Footprint Calculator https://www.footprintcalculator.org/home/en	(Internet)	GFN	Ongoing
EF review and criticism	Article	Data accuracy in Ecological Footprint's carbon footprint	Global	Jóhannesson et al.	2020
		Does the Shoe Fit? Real versus Imagined Ecological Footprints	Global	Blomqvist et al.	2013

Based on a personal investigation, it appears that the application of the ecological footprint model in Algeria are quite rare, and recent (from 2015), limited to the studies of Hachaichi (2019), Akrour and Grimes (2021; 2022), and some unfinished works (Dakhia's thesis and Zeggar's thesis). Similarly, investigation of the Mediterranean cities' EF is mostly recent and occurred after the GFN initiatives (GFN & MAVA foundation).

1.3.2. Criticism and evolution

The EF is yet to be globally recognized. However, its accounting system has been considered and integrated into the initiatives of 12 governments (Japan, Switzerland, Belgium), and numerous nongovernmental organizations (Whitby et al., 2014). The popularity and the various use of the EF has not been immune to criticism by users that Wackernagel and other experts define as vital to the development of the ecological footprint concept (Ewing et al., 2010; Harva, 2012; GFN, 2022a). Table 02 resumes some of the most regular point that reviewers have tackled and the methodological refinements considered by the founders of the EF.

Table 2. Resume of the criticism of the Ecological footprint and resulting modifications

Component	Criticism	Suggestion	Modification	Author' suggestions
EF outcome	One single measure cannot summarize or solve all the environmental complications which keeps increasing	Authors suggest combining this final aggregated form to a family of indicators, such as, Carbon footprint, water footprint	-	Galli et al., 2012
			Bottom up approach build on main component of a population demand	Simmons & Chambers, 1998 Simmons et al. 2000 Barrett, 2001
Land use	Some countries with high biocapacity appear at balance despite of their land use techniques and forms. This overlook consideration regarding sol clearing, intensive farming	Concrete land use information by sector, may be relevant for environmental impact assessment	Use of land use disturbance approach to identify consumption impact on the lands biological capacity and serve as providing EF measure for several scenarios	Lenzen & Muray, 2001 Van Den Berg & Grazi, 2013

Unproductive land	The EF estimate considers the extent of bioproductive areas, neglecting the importance of others (the dessert, icescapes) The biocapacity calculation are based on the Global Agro-Ecological Zones (GAEZ) to derive equivalent factors	Considering the land of “limited availability. Assessing earth biocapacity in terms of Net Primary Production covering the entire plant surface Taking into account human share and other species share on resources and space	Considering all land areas	Simpson et al., 2000
Land allocation for other species	The EF framework is built on human needs and human activities excluding other species demand and potential capacity. Assuming that a nation could be sustainable and appropriate 100% of the “useful” biocapacity		Appropriated Net Primary Production compared to available NPP (Applied in estimating the fishing activity impact on marine resources)	Talbert et al., 2006 Venetoulis et Talbert, 2008
Carbon sequestration land	The EF considers forest as the sole mechanism for carbon sequestration The calculation is entirely based on forest carbon sequestration rates	The carbon dioxide uptake by forests is not the only mechanism involved in the carbon cycle; forestry is not the only element that affects CO_2 exchanges between the biosphere and the atmosphere	The National footprint account is currently investigating accurate way to calculate the ocean and forest absorption of carbon dioxide	Ewing et al., 2010
	The EF considers a sequestration factor if 0.73 $tC.ha^{-1}.year^{-1}$ The sequestration potential varies significantly by forest types, plantations, and their biogeographic distribution: tropical and rain forests (7.1), temperate climates (1.8), boreal forest (0.5) The latter is inversely proportional Carbon emissions, which means that forest with the lowest sequestration potential are associated			

	with the highest carbon EFs			
Carbon dioxide	The EF only considers CO_2 as the main waste of the anthropogenic activity	Non-CO_2 greenhouse gases should be included in the calculation	Assessment of the EF using other GHG gases	Dias-Oliveira et al., 2005
The ecological footprint embodied in Trade	Consumption and trade of consumers goods	Product manufacturing and trade rely on input materials that also require land for production or sequestration. The EF should than consider embodied footprints (imported and exported hectares)	Use of Input-output analysis Use of life cycle analysis of products	Lenzen & Murray, 2001; Hubacek and Giljum 2003, Turner et al., 2007 ; Wiedmann et al., 2007

The Ecological Footprint has influenced the policies and communications of many governmental and non-governmental organizations (Holmberg et al., 1999; Blomqvist et al., 2013), urban planning expert also see this tool as a useful for policy design and planning (Wackernagel & Silverstein, 2000). However, the EF concept, its methodological approach, and outcomes have been subject to criticism since its formulation (Lenzen & Murray, 2001; Venetoulis & Talbert, 2006). Indeed, users and reviewers argued that the EF is not revolutionary, and not needed to inform policy-makers about global warming problems, overexploitation of marine resources, or deforestation (Van Den Berg & Grazi, 2013), and that given the magnitude of these problems the simple declaration of a "footprint" is only an attention grabbing device (Opschoor, 2000; Moffatt, 2000), or even misunderstanding of what the EF is trying to measure, thus, irrelevant for serious scientific or political context (Blomqvist et al., 2013). The criticism targeted general and specific parameters such the EF inability to describe the impact of unsustainable resources consumption and land use practices impacts on ecosystems. These comments have fuel the EF founders to review and integrate the suggested modifications in an ongoing process of development, maintenance and upgrades of the NFAs (Ewing et al., 2010). The modifications suggested by users has played a crucial role in refining the methodology, as the most interesting are considering the land state and the impact of land use using disturbance-based approach (Bicknell et al., 1997; Lenzen & Muray, 2001; Zhao et al., 2005), integrating life cycle assessment and input-output analysis to capture the EF of embodied flows associated with consumers goods (Lenzen & Murray, 2001; Hubacek & Giljum, 2003, Turner et al., 2007; Wiedmann et al., 2007; Moore, 2013; Akrour & Grimes, 2021). Accordingly, the GFN encourages countries to introduce appropriate modifications and contribute to the improvement of the method (Ewing, 2009), mainly through reliable figures, since the national accounts of the EF are built on synthetic data produced by international organizations (World Bank, FAOSTAT, IEA). However, downscaling the EF assessment requires more data, which means adjusting the calculation model and integrating other data-producing analyses.

1.3.3. Specification of the Ecological footprint

1.3.3.1. Ecological footprint and carbon footprint

It is essential to reiterate that the EF calculations only consider carbon dioxide (CO_2) in terms of the waste generated by human activities. In this case, the EF evaluates the equivalent absorption surface required (carbon sequestration footprint), considering the sequestering potential of forest ecosystems. By comparison, the carbon footprint is performed separately from the ecosystems' state and capacity, corresponding to an absolute emissions quantification or monetary value (Ewing et al., 2009; 2010). Moreover, the carbon footprint could be regarded as a sub-component of the ecological footprint.

1.3.3.2. Ecological footprint, biocapacity and global hectares

To better assess the impact of natural resource use, the final aggregate measure of EF associated with all uses is compared to biological capacity (BC). The GFN defines BC as the available area to produce biological materials used by humans and to absorb the waste they generate, taking into account prevailing management patterns and extraction technologies (GFN, 2022b).

Although both metrics are expressed in land area (gha), it is important to distinguish between EF, which is a hypothetical area needed for production (sequestration), and biocapacity, derived from an existing physical productive area. Indeed, both metrics are expressed in a standardized hectare (Uhde, 2009), the global hectare (gha), used for accurate comparison across countries (Wiedmann & Lenzen, 2007; Ewing et al., 2009; 2010).

In addition to a physical extent, this unit accounts for variation in yield and average productivity of productive areas obtained using a conversion coefficient (EQF) based on the global average agricultural land productivity (Global Agro-Ecological Zones GAEZ) (FAO, 2000; Uhde, 2009; Borucke et al., 2013, 2016; WWF, 2016; GFN, 2022b). Comparing the EF to the BC provides a diagnosis in terms of ecological balance. Accordingly, a state of ecological deficit (**equation 1**) results when EF exceeds BC, outlining that anthropogenic activity exceeds the capacity of ecosystems to regenerate goods and resources to support it.

Equation 1. Ecological deficit equation

$$Biocapacity\ [gha] - Ecological\ Footprint\ [gha] < 0 \qquad \text{Equation 1}$$

In contrast, a state of ecological balance or reserve implies that the capacity of ecosystems to support the development of human activity equals or outweighs the pressure applied by this activity (**equation 2**).

Equation 2. Ecological balance and reserve equation

$$Biocapacity\ [gha] - Ecological\ Footprint\ [gha] \geq 0 \qquad \text{Equation 2}$$

It is essential to reiterate that the EF model was primarily developed by economists wishing to measure the "quantity of nature" that humans to sustain their development. Therefore, the surfaces considered by the model are directly linked to his activity, ignoring some less-productive or non-productive lands.

1.3.3.3. Bioproductive areas

The world's bioproductive land area is estimated to be approximately 11.8 billion hectares (GFN, 2022b). Based on the IUCN classification, the NFA lists five productive land types, reflecting six land use categories, namely: cropland, grazing land, fishing grounds, forest land, and built-up areas (Wernert, 2007; Kitzes et al., 2008; Udhe, 2009; Borucke et al., 2013). For the sixth use category, carbon sequestration, the EF does not dedicate an exclusive area, assuming that all carbon uptake is applied to forest land, thus avoiding double counting (Lin et al., 2016).

Each biologically available and required area providing products and services needed by a given population are defined by the GFN as follows:

1.3.3.3.1. Cropland

It represents the available land to grow agricultural products including crops, livestock feed, aquaculture fish feed, oils and rubber. The GFN considers croplands to be the most biologically productive of all land types. The NFA uses FAO area and production statistics for more than 70 major crops to calculate this land (Kitzes et al., 2007, GFN, 2018). The biocapacity of crop areas cannot be exceeded by demand or production EF, as they are permanently labored and harvested (Lin et al., 2009; Borucke et al., 2013).

1.3.3.3.2. Grazing land

For this category, the EF assess livestock energy requirements (Ewing et al., 2009, 2010). Grazing land includes all grasslands used to feed animals, including cropped and wild grasslands (Ewing et al., 2010; Borucke, 2013). The productivity of these areas is based on the primary production data for tropical, temperate, and arid grasslands published in the Intergovernmental Panel for Climate Change report (Monfreda et al., 2004). Thus, the area of pasture required by a livestock product (meat, dairy, wool) is calculated using the amount of grassland needed to meet the total feed requirements of that product (Kitzes et al., 2007). This category is the most complex as it considers several components including the market supply of animal feed (e.g. Fish meal, fodder).

1.3.3.3.3. Forest land

These are the average areas of land required to supply forest products, such as wood for fuel and construction and wood derivatives (wood pulp for paper) harvested annually (Monfreda et al., 2004; Ewing et al., 2009; 2010; Lin et al., 2016).

The GFN also allocates to this category the task of absorbing a specific amount of carbon dioxide generated from fossil fuel combustion (Wernert, 2007; Ewing et al., 2009, 2010). It is noteworthy that the carbon uptake area is the largest component of the ecological footprint as most activities generate this waste (Kitzes et al., 2007; Ewing et al., 2009, 2010).

1.3.3.3.4. Fishing area

The fishing areas are the aquatic ecosystems (marine and inland waters) required to sustainably support a country's annual primary production and catch of marine and freshwater products (Lin et al., 2016; WWF, 2016; Ewing et al., 2009; 2010). The estimate of these areas is based on the principle of the maximum sustainable catch of fishery products, which is converted to equivalent primary production calculated based on trophic levels of the species caught (Ewing et al., 2009, 2010; GFN, 2018). The NFAs provide estimates of primary production requirements for 1 439 marine species and over 268 freshwater species (Lin et al., 2016).

1.3.3.3.5. Built-up land

According to the GFN, built-up surfaces are those covered by human infrastructure, such as roads, houses, industrial structures, and hydroelectric power reservoirs (Boev et al., 2016). According to the EF approach, this refers to the occupation of fertile bioproductive lands that have been physically altered by human activities (Lin et al., 2016). Therefore, associated with a loss of terrestrial biocapacity (Wernert, 2007).

1.3.4. Related and similar approaches

The Agenda 2030 sustainable development goals account for reducing carbon emissions, reshaping economic growth in a more environmentally responsible aspect, natural capital conservation, and development of renewable energy use. However, to achieve these objectives it is necessary to assess the current state of the resources. Accordingly, several indicators have been developed aiming mostly at assessing both human economic growth and the natural capital on which it relies. These two components are considered by the EF as it accounts for the required area to meet resource consumption needs and absorb the wastes generated by a human population. Comparable estimate are provided by other indicators such as human appropriation of net primary production (HANPP), environmentally weighted material consumption (EMC), land and Ecosystem accounts (LEAC), and economics of ecosystems and biodiversity (TEEB). The following table (**table 3**) describes the effectiveness and shortcomings of these indicators and their complementarity with the EF, based on Best et al. (2008), Galli et al. (2012) and (Bergossi, 2016) which answer in their document the ongoing questions and criticism regarding the EF and outline the main indications that the EF could provide in terms of sustainability.

Table 3. Ecological footprint and related approach

Tool	Concept	Impact measured	Strength	Shortcoming	Complementarity with EF
Ecological Footprint (EF) (Rees & Wackernagel, 1996)	Human dependency on natural resources and productive lands	Resources depletion Land use and land loss	Considers several human use including trade Relate human needs to carrying capacity	EFs do not account for impacts that are not associated with the regenerative capacity of a Typical land	-
Human appropriation of net primary production (HANPP) (Vitousek et al., 1997)	Amount of biomass appropriated by human economy	Impact on ecosystems and biodiversity	Provides a quantitative and spatially illustrated measure of human	Does not consider the demand associated with trade	EF output could be converted from hectares of bioproductive areas per year to kg of biomass per year

			pressure on ecosystems	Does not draw the establish an ecological limit	
Carbon footprint (Krey et al., 2014)	Carbon emissions inventory per economic activity in kg CO_2/year	Climate change	Carbon accounting could set limits on emissions, thus redefine the socio-economic growth	Focuses on the emission disjointedly from other related pressures on ecosystems	The carbon footprint is a sub-component of the EF which convert the CO_2 emissions into required carbon uptake land
The economics of ecosystems and biodiversity (TEEB)	Economic value of ecosystems and biodiversity in Dollars/year	Resources depletion	Mostly based on financial assessment. Some ecosystems' value cannot be standardized (cultural services)	Comparing economic growth and ecological benefits could be applied to assess the natural capital potential, and the possible risk related to resources loss	TEEB could be used to provide a value of the biocapacity (estimated by the EF). It can also support the EF' output especially the overshoot concept.
Land and Ecosystem Accounts (LEAC) (Ivits et al., 2020)	Provide an understanding of the land use	Land use Impact on ecosystems and biodiversity	Does not define thresholds Does not consider land use associated with trade Land use associated with some sectors such as industry is aggragated	Considers land use change overtime. Account for the maintenance costs of ecosystem	The monetary value estimate of land use and land use change could be integrated in the interpretation of the EF results, especially the "ecological deficit"
Environmentally Weighted Material Consumption (EMC) (Best et al., 2008)	Material consumption based on environmental impacts. Uses LCA's impact factors	human-health and eco-toxicity, ozone depletion, eutrophication, and acidification	Estimate of material flow could be subjective, as LCA' outputs differs and depend on the study boundaries and input data	The use of mass in "kg" is easy to understand. Covers a large number of LCA impact categories	The EMC data overlap with the EF underlying data, as material flow is the basis of EF accounting. EMC and EF can be applied at various levels

1.4. Ecological footprint and biocapacity assessment

1.4.1. Core equation

The EF calculation algorithm is based on a conversion equation (**equation 3**) that defines for each product consumed (or waste generated) an equivalent production area (or absorption area in the case of waste) (Boruck et al., 2013). This equation weights the local area, given in local hectares, into global hectares using conversion figures. The latter vary by product, country, year, and by type of surface, considering the specific features of each type of surface and use.

Equation 3. Basic equation for the EF calculation

$$EFp = \sum_i \frac{Pi}{Yn,i} \times YFn,i \times EQFi$$ Equation 3

Where;

- P_i: Quantity of a primary product i produced, or amount of waste (CO_2) emitted expressed in tonnes (tonne of CO_2 equivalent)
- $Yn_{,i}$: National average yield for product or commodity i,
- $YFn_{,i}$: Country-specific yield factor for a specific product i,
- EQF_i: Equivalence factor specific to a type of bioproductive surface of product i.

Similarly, biocapacity (BC) represents the production potential of a global hectare (Udhe, 2009). It is given by the following formula:

Equation 4. Basic equation for the BC calculation

$$BC = \sum_i Ai \times Yn,i \times EQFi$$ Equation 4

Where Ai, is the bioproductive area available for the production of each product *i* at the country's level expressed in local physical hectare “han”. The terms han (national hectare) and haw (world hectare) refer to the same unit as "ha". They are physical hectares, used to distinguish between national and global annual average yields. The diagram (**figures 2**) resumes calculation methodology.

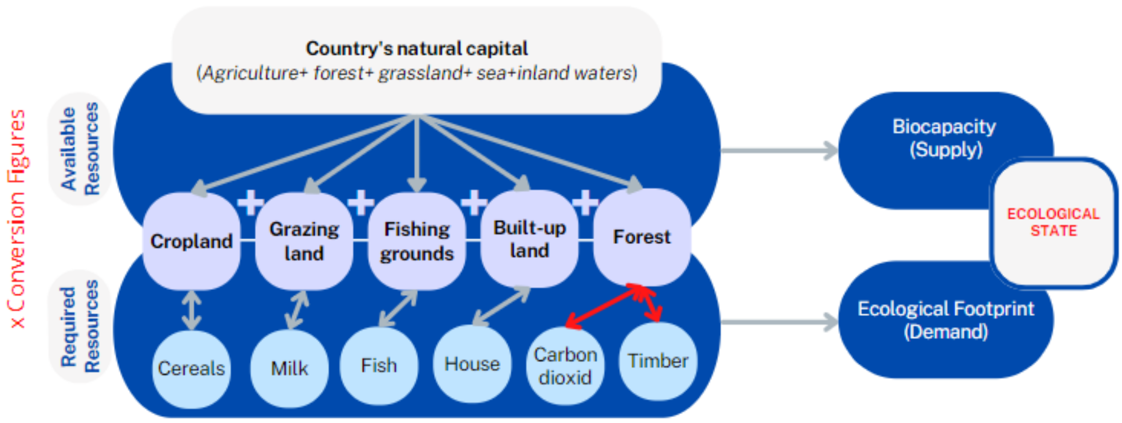

Figure 2. The ecological footprint, Biological capacity and Ecological balance

1.4.2. Conversion factors and calculation scheme

The main conversion factors in ecological footprint calculations are the Yield and the Equivalence Factor, defined as follows;

1.4.2.1. Yield Factor

Each country has its own set of yield factors given by bioproductive area categories. These figures are calculated each year based on the annual availability of usable commodities (Monfred et al., 2004; Ewing et al., 2009; Lin et al., 2016). It is the ratio between the national average yield and the global average yield of a specific product (Monfred et al., 2004; Wackernagel et al., 2004; Lin et al., 2016).

The YF for each type of bioproductive area (l) and country (N), is given by the following equation;

Equation 5. Yield factor ratio

$$ {}_{n}^{l}YF = \frac{Y_N^l}{Y_W^l} \qquad \text{Equation 5} $$

- $Y^l{}_N$: Represents the average annual yield factor of a given product of a given country expressed in tonnes.han^{-1}.
- $Y^l{}_W$: Represents the world average annual yield factor of a given product and for a given type of land use expressed in tonnes.haw^{-1}.

1.4.2.2. Equivalence Factor

The EQF represents a country's average potential productivity of a given bioproductive area compared to the world average potential productivity of all bioproductive areas (Wackernagel et al., 2004; Monfreda et al., 2004). This factor translates the productivity of a specific area into a national average (Wackernagel et al., 2004; Ewing et al., 2009, 2010). It is calculated using the spatial agricultural yield model, Global Agro-Ecological Zones (GAEZ) 2000, using the FAO Database Statistics (Ewing et al., 2009; Wiedmann & Barrett, 2010; Blomqvist et al., 2013; Boruck et al., 2013).

EQFs are specific to each land use type (Ewing et al., 2009; Ewing et al., 2010). However, they are the same for all countries, only changing slightly annually (Lin et al., 2016). The latest edition of the NFA lists the equivalence factors by type of bioproductive surface as follows; cropland 2.52 (hag/haw), grazing land 0.46 (hag/haw), marine and terrestrial fishing grounds 0.37 (hag/haw), and 1.29 (hag/haw) for forests (GFN 2019 set of YF and EQF). Moreover, the GFN's attribute the same EQF to the built-up land and cropland categories. Similarly, the EQF of carbon sequestration land equals that of forest land since the carbon footprint is assumed to be sequestered by forest ecosystems at 70% (Borucke et al., 2013; Lin et al., 2016). The general scheme of the national ecological footprint and biocapacity accounts are illustrated in **Appendix 1**.

1.5. Methodological approach

1.5.1. Top-down and bottom-up models

Several experts have recognized the usefulness of the EF in sustainability, urban planning, and resource management. These experts consider the EF a relevant communication tool that should be given in its aggregated form and detailed by component (Wiedmann & Barrett, 2010).

The standardized calculation model proposed by Wackernagel and Rees (1998) is referred to as a macro, compound-based, or top-down approach, which uses global-scale data (international level), and describes the final consumption for a given land use category (agriculture, fisheries). A new approach was developed a few years after the creation of the EF. The latter quantifies material and energy flows consumed by human activities (Barrett et al., 2002). This approach supports socio-economic and environmental policies based on locally produced statistics and allows for a bottom-up analysis (Monfatt et al., 2005). Simmons and Chambers first reported this methodology in an article describing the EcoCal software (Simmon & Chambers, 1998).

The component-based approach calculates the EF of all significant components of a population's resource use and waste generation (Simmon et al., 2000; Monfreda et al., 2004). This method is ideally used at the city scale, accurately capturing resource consumption. Indeed, bottom-up methods are based on life cycle assessment (LCA) studies for considered products and processes. The LCA's outputs are then converted into overall conversion figures, allowing for highly detailed LCA inventories and a more accurate description of the products consumed (Sala et al., 2020).

In the component-based EF, the calculation starts with identifying each component based on locally relevant data. This model enables a detailed assessment of the city's metabolism, integrating material and energy flow budgets (urban metabolism) into the LCA (Simmon et al., 2000; Monfatt et al., 2005; Moore, 2013). Therefore, the final result's accuracy is driven by the exhaustiveness of the components' inventory and the reliability of LCA's outputs (Monfreda et al., 2004). Finally, for a given population and a defined period, the component-based EF provides an estimate of human demand on each of the land types previously described in the original Wackernagel method: cropland, grazing land, forest, built-up land, and fishing grounds, as well as energy land (carbon sequestration land). Indeed, this approach maintains the central structure while focusing on the small-scale activity instead of aggregated consumption (Barrett, 2001). Both methods are complementary. Indeed, the top-down (original) method covers all final consumption categories, providing a broad scope of all activities (national fisheries production's consumption), and the bottom-up method delivers more details and allows to target a category of consumption (energy consumption during fishing).

Considering the scale, the component approach requires large input data sets. Therefore, the calculation method adopted in this work integrates urban metabolism analysis as a preliminary step and a data generator tool for the EF estimate. Indeed, the study will first present an inventory of three main components, namely biological resources (Material), energy consumption (Energy), and associated infrastructures (Built land).

1.5.2. Integrated analysis

The bottom-up model requires specific inputs. The data describing the previously described component are obtained through an analysis of urban metabolism and life cycle of each activity.

1.5.2.1. Urban metabolism

Urban metabolism refers to the total sum of technical and socio-economic processes that occur within cities, including growth, energy production, and waste disposal (Kennedy et al., 2007, 2011). Comparable to a living organism's metabolism (ecosystems), urban metabolism analysis (UMA) implies investigating the "city" system as a living system governed by input and output flows, whereby the incoming flow reflects the supply of materials (natural resources) and energy, and the outlet flow reflects the production and waste resulting from the production processes (Guyonnaud, 2009). Wolman (1965), a leading pioneer, explicitly described urban metabolism and applied the laws of thermodynamics in his article "Metabolism of cities," which he described as the materials and commodities needed to support the city's residents in the various environments they occupy (Wolman, 1965). Therefore, the UMA investigates resource users' lifestyles and consumption patterns through associated goods and services (Di Nardo, 2016). In addition, it provides an understanding of such a complex system as a city by considering specific components, including economic activities (Wolman, 1965; Kennedy et al., 2007, 2011; Bancheva, 2014). UMAs operate within an accounting framework and have been integrated into several fields, including ecological accounting and urban ecology (Bancheva, 2014; Movahedi & Derrible, 2021). Consequently, and in line with sustainable development objectives, particularly those targeting climate change mitigation and, thus, GHGs (CO_2), UMA analysis is often used to identify activities or processes that emit the most CO_2 (Derrible et al., 2021). Hence, it can be associated with analysis to improve environmental impact assessment, namely life cycle analysis (LCA), such as transportation, water, and electricity LCA (Goldstein et al., 2013; Moore, 2013; Butt et al., 2018; Maranghi et al., 2020; Butt et al., 2020). Indeed, associating the LCA with UMA enables an assessment of the sustainability of an urban system (Maranghi et al., 2020). Figure 3 bellow depicts for the "dwelling" system the overall input flows of material (construction materials), energy (industry and conditioning), land use, and output flows (greenhouse gas production).

UMA could be applied to such a system to investigate its impact on the supporting environment.

1.5.2.2. Life cycle assessment

According to ISO 14040:2006, the life cycle of a product system consists of all successive

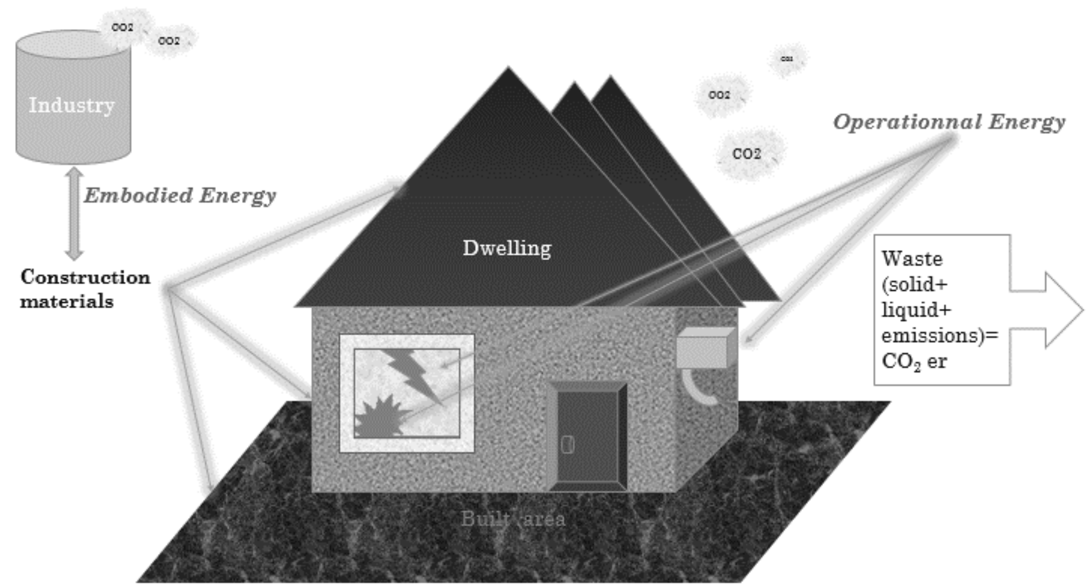

Figure 3. Energy and material flow associated with dwelling

phases from raw material extraction or natural resource generation to disposal and waste treatment (ISO, 2021). It is a comprehensive analysis of the environmental impacts of a system that includes all activities associated with a product or service (Rousseaux, 1999; Grisel & Osset, 2004). This approach quantifies the input and output flows of materials and energy at each stage of the life cycle, and are frequently used, particularly in industry, to consider the environmental component (Lenzen, 2001). Typically, LCA comprises four main stages, namely goal and scope definition (setting the study boundaries), life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and life cycle interpretation (Inaba, 2004; ISO, 2022).

LCA is conducted through specific software (e.g., SimaPro, OpenLCA) using processes database (e.g., Ecoinvent), updated with the users' modeling results. LCA is an emerging science in Algeria and is currently used in several sectors outside the industry. Indeed, a literature review (**table 4**) shows that LCA studies were initiated a decade ago (2010), with the first applications in the cement industry (REF), agriculture (irrigation and fertilizers) (Makhlouf et al., 2019; Redouane et al., 2018), wastewater treatment (Messaoud-Boureghda et al., 2011; Mohamed–Zine & Hamouche, 2016), building materials (Boughrara et al., 2015; Dakhia & Zemmouri, 2021), and more recently in aquaculture which Lourguioui et al. (2017) consider as necessary to inform management policies for such activities.

Table 4. Examples of LCA studies in Algeria

Year	Product	LCI database	Software	Author
2011	Industry (Oil drilling)	Local data	SimaPro	Ghazi et al.
2012	Industry (Recycled water)	Local data+ Ecoinvent	SimaPro	Messaoud-Boureghda et al.
2013	Industry (Drinkable water)	Local data	SimaPro	
2015	Agriculture (Ammonia)	Local data	GEMIS	Makhlouf et al.
2015	Agriculture (Milk production)	Local data+ Ecoinvent	SimaPro V7	Younsi
2017	Aqua-farming (Mussel)	Local data+ Ecoinvent V3	SimaPro	Lourguioui et al.
2017	Agriculture (irrigation)	Local data	ISO 14040 standers	Azeb et al.
2018	Agriculture (fertilizers)	Local data	ISO 14040 standers	Redouane et al.
2019	Agriculture (fertilizers)	Local Dara	GEMIS	Makhlouf et al.
2021	Construction (energy performance)	Local data	ISO 14040 standers	Dakhia & Zemmouri

CHAPTER 02
Study zone: Wilaya of Algiers and Tipaza

CHAPTER 02. Study area: wilaya of Algiers and Tipaza

2.1. Choice of analysis

It is currently accepted that there are various sustainability, resource and environmental status indicators. However, it is complex to impose a universal approach to environmental accounting because of the differences between countries and regions of the world, the distribution, the nature of goods and resources, and their use patterns. In the caseof the ecological footprint EF, the Global Footprint Network GFN encourages countries to establish their own national or down-scaled accounts NFA mainly for monitoring their development and for data dissemination. Indeed, the description of the "Algerian" case by the GFN is one of the reasons for undertaking this analysis. In its open-data platform, the GFN (2022) presents Algeria as a country in an ecological deficit since 1974, with a continuously growing national EF that has reached 2.3 gha/inhabitant, i.e., an Algerian citizen appropriates more than two hectares of the world's average production, whereas Algeria's population have less than one global hectare.

Detailed by sector of activity or category of surface area use, according to the principle of the EF, this deficit is manifested in the agriculture sector (cropland), forest products and CO_2 sequestration surfaces, with ecological deficits of 0.23, 0.13 and 1.33 gha/capita, respectively (GFN, 2022a). The country is in an ecological balance in the fisheries and grazing land sectors. Nevertheless, the NFAs are based on international synthetic data in most cases. Therefore, in addition to this factor, the ambition of this work is to link top-down (standard, original model) and bottom-up approaches to obtain a multilevel diagnosis and to assess the sustainability of the activity on a reduced scale with locally produced input data. In this perspective, the study area comprises two coastal wilayas: Algiers and Tipaza.

2.2. Selection of the study area: Coastal wilayas

2.2.1. Activity

Aiming to perform a comparative analysis between two cities with different levels of development, depending on the intensity of activities and their requirement for natural resources, the wilayas of Algiers and Tipaza were selected for an analysis of their respective EF and BC. Algiers is an important development pole due to its status as the political and economic capital of the country. This wilaya is also recognized as the main metropolis of the country. By comparison, the wilaya of Tipaza,with an agricultural and tourist vocations, is in a transitional situation in term of development with less intense activity. Moreover, the agricultural and tourist potential of these wilayas is not fully exploited, particularly tourism, which is limited to the coastal area and summer season. The contrast between both wilayas is insightful and enables to explore the potential and probably foreseeable differences in their EF.

2.2.2. Location

The second criterion for this selection is linked to the geographical location of the two coastal wilayas, as both are located in the North of the country on a narrow coastal region, representing less than 4% of the surface of the national territory. However, this part of the country presents a stronger attraction for the population and the socio-economic activities. This attractiveness is linked to the proximity of the sea (fishing, seaside tourism), to the existence of coastal plains favorable to grazing, agriculture and arboriculture, as well as the forestry heritage favoring forestry, tourism and recreation. Furthermore, the availability of facilities for the social well-being and development. The coastal area is also characterized by the presence of major public facilities and infrastructure (e.g., ports, airports, roads, seawater desalination plants).

The wilaya of Algiers is also selected due to its high population and the ongoing various economical and industrial activities. Moreover, it constitutes a representative case that should provide an overview of the ecological state of the country. The Analysis of developing regions like the wilya of Tipaza, where it appears that less natural resource is exploited, enables a proportional comparison with other cities based on the resources exploitation rate and practices.

2.3. Study model

In addition to considered wilayas, the model scheme and applicability was one of the factors requiring a rescaling of the study area, primarily considering the amount of data needed for the calculation and knowing that some data are provided at an even smaller scale (municipalities, management bodies, user). Indeed, this last criterion is directly linked to one of the thesis objectives, namely to confirm the applicability of the model at a reduced scale, taking into consideration the calculation framework provided by the GFN. Accordingly, the bottom-up model applied is assumed to deliver accurate output to rebuild the typical land use categories of the original model.

2.4. Year of study

The year of study (2015) was chosen first to ensure a comparison objective with the latest national accounts of Algeria for the year 2014 provided by the GFN (**Appendix 2**), describing Algeria's EF and BC in 2014. Furthermore, 2015 was marked by important international agreements on environmental and climate issues, in particular the adoption, of the framework of the United Nations Agenda on Sustainable Development, the 17 Sustainable Development Goals in 2016 SDGs. This year was also marked by COP21, where the international community adopted the Paris Climate Agreement which entered into force the following year. At the national level, the first national strategy on integrated coastal zone management was adopted in 2015. Algeria's Nationally Determined Expected Contribution (NDC) to the UNFCCC was submitted during in 2015, along with revisions to the country's national strategy on renewable energy and energy efficiency.

2.5. Presentation of the study zone

The study zone includes the wilaya of Algiers and Tipaza (**figure 4**). In this section the presentation of these two wilayas follows the EF standard model's design which considers both the availability of goods and resources (BC) and the demand for this biocapacity (EF). Thus, the first part highlights the assets of the two wilayas in terms of area and natural resources available for conservation, protection and use. The second part is dedicated to the description of the main activities taking place in the two wilayas, i.e., fishing, agriculture, farming, and urbanization, as well as the generated waste.

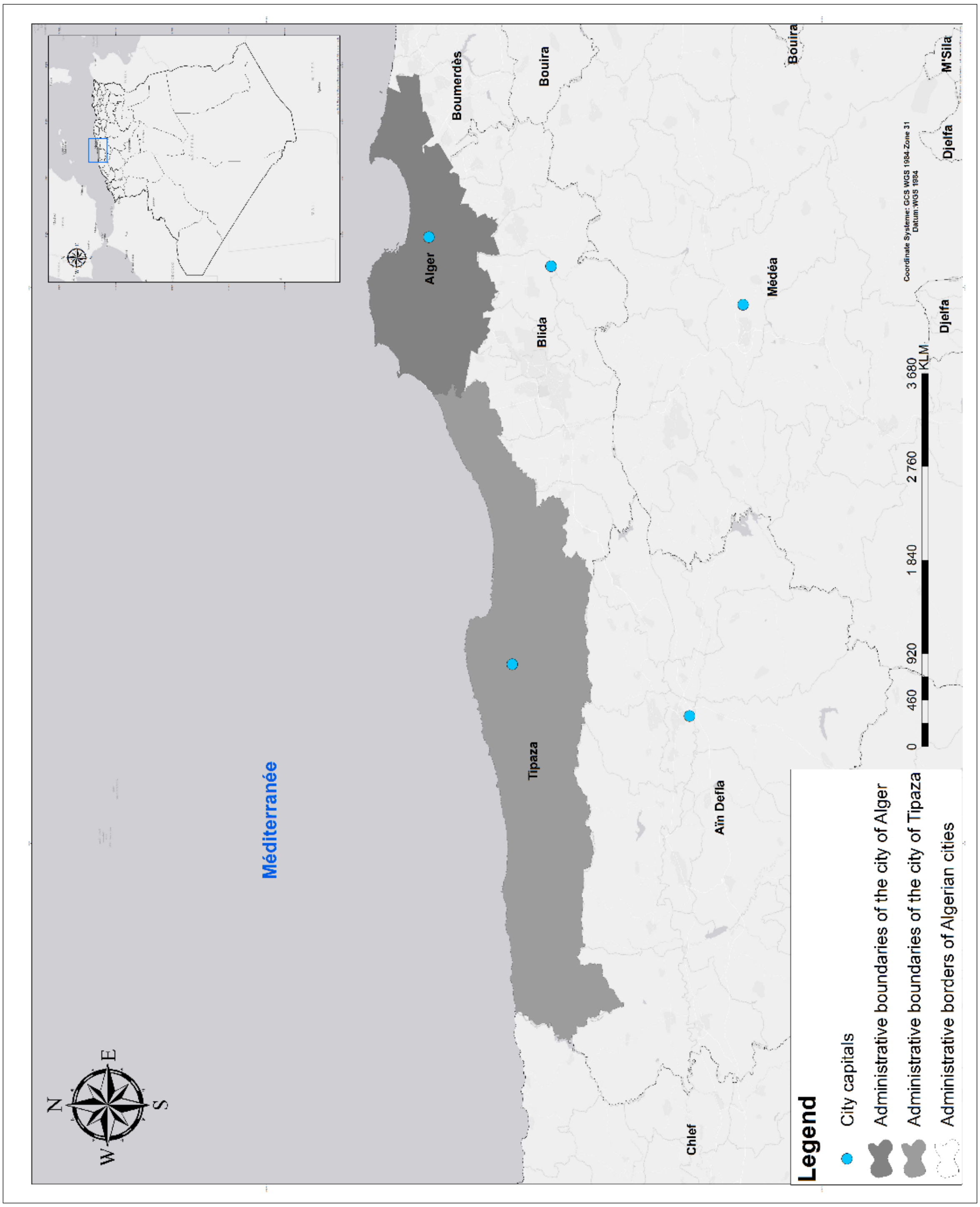

Figure 4. Geographical location of the considered wilayas

2.6. The wilaya of Algiers

2.6.1. General description

Algiers is the capital of Algeria, located between latitude 36° 46′ 34″ North and longitude 3° 3′ 36″ East, in the North of the country. It is bordered by the Mediterranean Sea to the North, by thewilaya of Boumerdès to the East and by the wilaya of Tipaza to the West, constituting the central sector of Algeria (**figure 04**). The wilaya of Algiers is bordered to the South by that Blida. Algiers is one of the country's main urban areas and ranks seventh in Africa in terms of population with almost three million inhabitants and a density of 4056.97 inhabitants/km² (Monographie/Algiers, 2019). The wilaya has 57 municipalities hosting, in which more than 30% of the total population of the wilaya located in the coastal area. The eastern municipalities are the most populated and the broadest in terms of surface, marked by lower densities compared to central municipalities (Bad El Oued, Casbah, and Bachdjerah) that reveal about 30 thousand inhabitant/km² resulting from the increase of demography in these zones, where urbanization land is insufficient. The coastal line of the wilaya extends from the West, commune of Zéralda, to the East, commune of Réghaïa, over 107 km and on a narrow width in the center and wide towards the western and eastern limits.

2.6.2. Natural potential of the wilaya

Based on the recent wilaya's profil description (Monographie/Algiers, 2019), the capital extends to 809.22 km² characterized by three longitudinal zones, namely the sahel represented by gradually sloping hills, a relatively flat coastline comprising mainly sandy beaches interspersed with rocky plains and the Mitidja which is one of the fertile surfaces of the Northern region favored by the Mitidja aquifer. These features enhance the development of the agricultural activity in an area that has reached about 40% of the wilaya with 16 thousand ha of irrigated land in 2019. The wilaya's natural heritage also includes areas of grassland used for livestock that are estimated to be 4 thousand ha, unused areas for agriculture that are exceeds 43 thousand ha, and about 5 000 ha of forest areas (6% of the wilaya's territory). Forest comprise urban woods of less than 10 ha (Bois des Cars, Talus de la Concorde), as well as large wooded areas up to 600 ha (Forêt des Planters, Baïnem, Bouchaoui). Algiers has a temperate Mediterranean climate with an average annual temperature of 18°C and rainfall varying between 670 to 800 mm. year^{-1} with marked maximums during the November-January period (Monographie/ Algiers, 2016). This rainfall supplies a network of dams such the Keddara dam, Hamiz (surface water), 251 wells (groundwater) with a flow rate of 320,000 m^{3}.day^{-1}, and natural water sources such as Source Cherchar (Jardind'Essai, Algiers) and the two basins Source (Ben Aknoun). Moreover, Algiers counts nine Oued[1], and three stations Hamma (Algiers), Fouka (Tipaza) and a mono-block station at Palm Beach (Zéralda). The total drinking water production capacity of more than 1 500 000 m^{3}/day for a demand of less than one million m^{3}, where the supply is estimated at 165 liters. inhabitant $^{-1}$.day^{-1} (Monograph/ Algiers, 2016). The availability

[1] Oued Smar, Oued Ouchaiah, Oued Kniss, Oued El Kerma, Oued El Hamiz, Oued M' kacel, Oued Reghaia, Oued Beni Messous

of resources is a driver for the settlement and the expansion of the population and the development of socio-economic activity.

2.6.3. Socio-economic activities

2.6.3.1. Agriculture and livestock

The useful agricultural area (SAU) of the wilaya of Algiers is estimated at about 29 thousand ha, i.e., less than 1% (0.34%) of the national SAU. These area is distributed in cereal area (7%), forage area (0.8%), vegetables crops (3%), fruit trees (3.7%) and vines (grapes) (7.7%). The total surface area used for agriculture in Algiers also includes pastures and gazing land dedicated to animalhusbandry, comprising 37 545 heads of sheep, cattle, goats and horses. These surfaces are distributed in an inequitable way, where the vastest grazing lands (exceeding 100 ha) are located towards the South of Algiers (Sidi Moussa, Khrassia, Eucalyptus) with the exception of Ain Benian and Cheraga. In contrast, some municipalities of Algiers are devoid of agricultural and pastoral surfaces, such as Bab El Oued, Ben Aknoun, Bouzareah, Dely Brahim, Hammamat, Hussein Dey and Sidi M'Hamed. The agricultural production in Algiers reached 52 230 Qx of cereals (24% Durum wheat), 189 000 Qx of fodder, 3 063 300 Qx of vegetable crops, 645 120 Qx of arboriculture (fruit trees), and 300 020Qx of vine. The bulk of the agricultural production in Algiers is held at the eastern municipalities, such as Rouiba, Dar El Beida, Baraki, Birtouta and Eukalyptus, particularly for, cereals, fodder and viticulture. Moreover, the western municipalities such as Staoueli, Zéralda and Mahalma are marked by an important cropping arboriculture. Conversly, the center municipalities of the wilaya, such Kouba, Mohammadia and Bir Mourad Raïs, are associated with low production. The commune of Bab Ezzouar has the lowest agricultural production.

2.6.3.2. Forestry

The vegetation grounds of the wilaya of Algiers cover 5 000 ha in 2019 against 4 942 ha in 2015. The forest heritage comprises essentially Aleppo pine (39%) and maritime pine (33%), which are present in the coastal municipalities and neighboring municipalities (la forêt des planteurs Zéralda), with other species, such as Eukalyptus (3%), Eukalyptus and Aleppo pine (mixed forest) (11%), shrub (2%), cork and oak holm.

The Directorate General of Forests (DGF) 1999-June 2018 activity report shows that no pastoral planting happened in the wilaya of Algiers. The latter had only known a a small amount of reforestation (21 km²) and less than one km² of fruit plantations (DGF, 2018). The forest areas of Algiers' wilaya serve mainly as places of entertainment and recreation in addition to providing forest products. The wood production estimated at 23 574 m^3 in 2017. Despite a 52% drop between 2016 and 2017, this production is seven times the production of the wilaya in the past 20 years. The DGF statistics rank Algiers first in the forest product's processing in Algeria (DGF, 2018), as it counted in 2019, almost 900 companies in the wood and paper industry (Monographie/Alger, 2019).

2.6.3.3. Fishing

The wilaya of Algiers features a maritime area of 1 326 km², offering an average annual production of 3 841 tonnes, with an average contribution of less than 4% to the national fisheries production (ONS,2013; 2017; 2019). This production is distributed over four ports, including a fishing and commercial port (Algiers), a fishing and recreational port (El Djamila), a fishing port (Tamentfoust) and a fishing shelter (Raïs Hamidou), housing 321 boats, including trawlers, sardine's vessels, and small scale-vessels in addition to a total of 1 448 yacht boaters. The production of the fisheries of Algiers is dominated at 91.2% by blue fishes, followed by white fishes, shellfish, sharks and molluscs with a low proportion. In addition, the fishing activity in the wilaya of Algiers is complemented by the processing of fishery products by four companies occupying an area of 900 m² for a production of 99 tonnes (Monographie/Alger, 2016).

The fishery production is governed by environmental parameters (narrow continental shelf, strong east and west winds, Atlantic current) which affect the Algiers sector. Therefore, the availability, the development and the distribution of the biomass (Chalabi and Akkacha, 1998), as well as the socio-economic factors such age and characteristics of the fleet. This last factor is represented by trawlers, sardiniers and small boats of 20, 12 and 7 metres in an average length (SGPP, 2019) and with an average engine power of 450 (trawler), 240 (sardinier), 24 (small boats) and horses.

2.6.3.4. Tourism

The Mediterranean fronting is the principal asset of the wilaya of Algiers. The eastern maritime facade of the wilaya of Algiers called bay of Algiers, which is included between the cape of the Pointe Pescade (Raïs Hamidou) in the West and that of Matifou (Bordj El-Bahri). Tourism in Algiers is dominated by business tourism and seaside tourism, with 53 hotels offering seaside facilities. The wilaya has the largest number of bathing beaches, exceeding fifty beaches (Alloui, 2012). The leisure and recreation areas vary in the wilaya of Algiers including hotels (251), ranked restaurants (54), thalassotherapy establishments (1) and other accommodation (4). The touristic infrastructure of the wilaya of Algiers counts 13 touristic extension zones (ZET) of approximately 27 km ², where the largest is that of Ain Chrob (1 and 2), accounting for 5% of the national ZET. The coastal ZET surface is already consumed at more than 400 ha. In addition, the wilaya's tourism development plan included a total of 32 tourism investment zones in 2015. The historical sites of the wilaya of Algiers recalls the story of the various Souhier civilizations that settled in the region. In this case, the mosques (Djamàa El Kebir, Ketchaoua), the Kasbah of Algiers, which has been designated a world heritage by the UNESCO, the Algiers Gates (Bab El Djazira), and the museums (national museum of Islamic arts) have all become popular tourist destinations for both the local population and visitors (national and international).

In spite of its favorable geographical location and Algiers' wilaya landscape and historical assets, the tourism in the wilaya of Algiers, is hindered by several factors, namely the management of this activity (Souhier, 2020).

2.6.3.5. Urbanization

Urbanization occupies more than 45% of the surface area of Algiers' wilaya (36 500 ha). Indeed, wilaya is experiencing an urbanization growth rate of 66% (1640 ha/year) (Seba, 2012; Rabehi et al., 2018). Despite its small surface area and the challenges linked to urbanization (centered population), the wilaya of Algiers is home to more than three million inhabitants (7% of the Algerian population). The distribution of the population is more dispersed in the eastern and South-East (Baraki, Birtouta, Ouled Chebel), as well as some western municipalities (Zéralda, Chéraga), with lower densities than the average (4873 inhabitant/km²). The density per km² increases while moving towards the central municipalities (Bab El Oued, Casbah, Sidi M'hamed, Bachdjarah, Algiers centre, Belouizdad) mainly because of their surface which does not reach 2% of the territory of the wilaya. The city of Algiers has undergone numerous urbanistic mutations engendered by the different periods of pre-colonization, conquest urbanization, construction of Greater Algiers, illicit occupation of the land after colonization, installation of shanty towns (slums), spontaneous and highly centralized development (Monographie/Alger, 2016; Hadjiedj In Hadjiedj et al., 2003). The development of activity in the wilaya of Algiers at the beginning of the industrial era (1976), requiring more functional space beyond the center, led to the creation and implementation of development plans (POG[2] and its committee COMEDOR[3]). Producing a set of new urban housing zones (ZHUN) installed towards the east of the wilaya, as well as governmental (Cité gouvernementale in Bordj El-Kiffan), economic (Cité des affaires économiques in Mohammadia) and poly-centers (Du Chazaud, 2020; Hammache, 2003). Other instruments have followed with the aim of decongesting the center of the city of Algiers and creating activity zones. The PDAU[4] was developed and based on the guidelines of other tools, such as the SDAAM[5] aiming to transform Algiers into the first metropolis of Africa and the PACMA[6], which is a program that guides the implementation of the national environmental strategy established by the law 02-02[7] (PDAU/Alger, 2009). However, these urban planning instruments deployed with the aim of providing planning orientations and the use of space in Algiers still struggle to manage and overcome all the constraints of Algiers, a wilaya that does not meet the needs of a constantly growing population, and where residential areas and activity zones are in conflict with other land use such as roads and transport networks (Baouni, 2011).

2.6.4. Urban fabric

The economic development of the wilaya of Algiers is declined by its spatial organization in economic infrastructures and complementary equipments. The urban fabric of Algiers' wilaya consist of:

2.6.4.1. Dwellings and individual houses

The housing occupation rate (TOL) reached 4.97% for a total of 672 311 housing units, comprising different dwelling programs, (participatory, rent-to-own, social renting). Resulting from the old urban plans, East and center municipalities of the wilaya of Algiers have the highest number of housing units, exceeding 15 thousand units per commune. The real estate stock was reinforced by more than 40 million units from 1999 to 2018, of which 30% were built in rural areas. Indeed, these achievements have enabled the rehousing of more than 2500 precarious sites (Slums, bungalows, informal settlements, basements and outdoor terraces). The real estate stock of

[2] POG General Orientation Plan
[3] COMEDOR Permanent Committee for the study, development, organization and planning of Algiers
[4] Master Plan for Urban Development and Planning
[5] Master Plan for the Development of the Algiers Metropolitan Area
[6] Coastal Development Program for the Algerian Coastal Zone
[7] Law 02-02 of 5 February 2002 on the protection and development of the coastline

Algiers also includes the construction of 514 744 individual houses, including 8.9% of precarious dwellings against 9.36% during the last census.

The attractiveness of the wilaya of Algiers also lays in the availability of public services, allowing the population to settle and maintain its activity. The wilaya includes the main institutions and administrative structures. In 2009, Algiers' wilaya accounted for 2030 public facilities, including health facilities (e.g., 4 university hospitals), education (1207 facilities for the three cycles), in addition to sports, social assistance and culture (PDAU/Alger, 2009).

Moreover, the strategy of urban planning also includes the creation of new cities. Indeed, the wilaya of Algiers currently counts in its western extension the new city of Sidi Abdellah in the commune of Mahelma, Zeralda, Douéra and Souidania, extending to 7000 ha (45% urbanized) and a capacity of 450000 people. In addition to 34 completed equipment (out of 70) and 11 operational investment projects (MHUV, 2022). The new municipality of Bouinen is also included in the perspective of decompression of the urban pressure on Algiers municipality. It extends over more than two thousand hectares for about 36 000 housing projects, 204 equipment, and five investment poles (MHUV, 2022). These two cities projected as a pole of excellence and competitiveness ensuring all the necessary conveniences for the residents, also they represent a new source of consumption and transfer of goods and energy with old municipalities.

2.6.4.2. Roads

The road network of the wilaya of Algiers extends over 2 364 km and has a road density of 2.14 km/km² (Monographie/Alger, 2016). In line with its rugged terrain and coastal position. The network includes communal roads, wilaya roads, national roads and a highway.

2.6.4.3. Port and airport works

The wilaya of Algiers has one international airport, namely Houari Boumediene, which covers more than 600 ha (28% of the commune of Dar el Beida) for a capacity of six million annual passengers.

The wilaya is also well served in terms of port infrastructures, comprising the Port of Tamentfoust (El Marsa) with a surface of 3 ha, the national Port of Algiers for fishing and trade with a surface of 184 ha, the port of El Djamila (Ain Benian) covering 2.7 ha and the port of Sidi Fredj (Staoueli) with a surface of 2.5 ha.

2.6.5. Waste management

Resulting from the anthropogenic activity, wastes in the wilaya includes three forms: air emissions, solid and liquid waste. Air emissions are mainly represented by greenhouse gases GHGs, especially carbon dioxide (CO_2) from the combustion of fossil fuels. Although it is included in the national strategy to reduce these emissions and control the associated effects (temperature increase), this component is poorly investigated at the wilaya level.

Solid waste management includes urban waste from household consumption, namely household and similar waste (DMA), industrial waste and hazardous waste (e.g., hospital waste). Accordingly, the wilaya of Algiers counted five landfills: Baba Ali-Birtouta, Hamiz-Bordj El Kiffan, and the uncontrolled landfill of Oued Smar and that of Ouled Fayet both rehabilitated into a public garden. Currently Algiers comprise one centered landfill of 95 ha located in the west of the wilaya in the commune of Mahelma allowing the treatment of household and similar waste and resulting leachate treatment, and construction waste.

The management of liquid waste is known as urban wastewater. The rate of connection to the sewerage network of Algiers is 98% allowing the recovery of about 480 thousand $m^3.day^{-1}$, treated at four stations (Réghaïa, Baraki, Beni Messous, Staouili), with a treatment capacity of 75%.

2.7. The wilaya of Tipaza

2.7.1. General description

The wilaya of Tipaza is located at about 70 km to the West of the Algiers. The northern side of the wilaya faces theMediterranean basin. The wilaya covers an area of 1 707 km², of which more than 40% is plain, 34% is hills and 20% of mountains (Monographie/Tipaza, 2020). The wilaya of Tipaza is located in the Algerois sector (**figure 4**). This wilaya borders on a highly urbanized region, namely the wilaya of Algiers, and Blida. Hence the high the population, which attracted by economic (Algiers, Blida), agricultural (Mitidja) and industrial (Blida) activities.

Tipaza comprises 28 municipalities, including 13 coastal municipalities which occupy a total surface area of approximately 670 km², hosting 57% of the total population of the wilaya with an increasing surface area from East to the West. The coastal municipalities are marked by a strong urbanization estimated at 36% of urbanized coastal line at the level in eastern municipalities (from Tipaza to Douaouda). The municipalities of the western region of Tipaza are larger (over 70 km²). These municipalities are marked by a low population compared to the eastern municipalities such Kolea, Fouka, and Hadjout, where the density is 2 to 3 times the average density of the wilaya. This is explained by the fact that the eastern municipalities such Bou-Ismaïl are included in the western extension of the wilaya of Algiers, in addition to the history of the western municipalities of Tipaza, which has prevented the settlement of the population. Conversly, the western and south-western region of Tipaza (Messelmoune, Larhat, Aghbal, Beni Milleuk, and Menaceur) comprise a significant natural heritage consisting of a variety of sites, including forest and recreational gardens, sandy and rocky beaches, the chain of hills of the Tellian Atlas, and the imposing Mount Chenoua.

In addition to its tourist appeal, the wilaya has strong assets that can captivate and interest the neighboring population. However, compared to Algiers, its territory remains relatively unaltered by human activity.

2.7.2. Natural potential of the wilaya

As a result of its location, Tipaza has a Mediterranean climate between sub-arid and humid, with two bioclimatic trends: a minimum temperature of 9.3°C linked to the topography, the sea and the vegetation (Khoualdi, 2012), with 675 mm average rainfall, of 79% (445.5 mm) of the annual rainfall is recorded from November to April (Monographie/Tipaza, 2014). This precipitation supplies the wilaya's various water sources, including groundwater, surface water such Mazafran, El-Hachem, Djer, Damous Ouds, as well as the dams, particularly the Boukerdene dam in the commune of Sidi Amar with a capacity of 145000m^3 and an approximate

33% filling rate, the hillside reservoirs of Attatba (Ain Zouaoua) and Hadjret Ennous (Mouloud Azizi) which are currently 100% silted for the first and not exploited for the second. The total storage capacity of the wilaya is estimated at more than 190 miles m3 allowing an average daily supply of 260 l/inhabitant.

Tipaza is also known for its wide forest areas. The Tipaza forest covers 40 315 ha, i.e., 23.6% of the wilaya's territory. The rehabilitation and preservation of this forest heritage is performed through national or sectoral reforestation programs (Bellout & Foudih, 2016).

However, forests are unevenly distributed throughout the wilaya, as 68% of the total are located in the West of the wilaya (Damos, Cherchell, Gouraia, and Sidi Amar). The hydrographic network in the wilaya of Tipaza allows the development of agricultural activities, which represent one of the most important activities of the wilaya, especially in the Mitidja plain in the south of the wilaya. The richness of the vegetation of the wilaya of Tipaza is also present under its marine waters which cover remarkable coastal and marine habitats, in particular the meadows of Possidonia which contribute to the growth of the halieutic biomass of the wilaya (shelter, source of nutrients and place of reproduction for fish). The development of fishing activity also relies on the Chenoua marine area of 2 382 ha, which is in the process of being classified (FEM/UNDP, 2003), in addition to the strategic areas of Kouali to the East and Cherchell to the West.

2.7.3. Socio-economic activity

Due to its coastal location, the environment that surrounds it as well as the climatic conditions that prevail in the region, the wilaya of Tipaza is known for the richness of its agricultural land, its fishing areas and its attraction for tourism and recreation.

2.7.3.1. Agriculture and livestock

Tipaza’s wilaya most dominant activity is the agricultural. This activity is described as self-subsistence agriculture, especially as the land is sloping, and each rainfall generates significant runoff (Bouaïchi et al., 2006). The SAU of the wilaya of Tipaza covers 61 799.8 ha, i.e., 36% of the territory of the wilaya, which testifies to the importance of agricultural activity in the region. The irrigated agricultural area in 2019 was estimated at more than 23 520 ha compared to 19 148 ha in 2014 (Monographie/Tipaza, 2020).

The crops grown on the wilaya's land vary according to the nature of the soil, with vegetable crops associated with the largest part 27% of the SAU, followed by arboriculture (24%), cereals (23%), fodder (12%) and to a lesser extent, viticulture, dry vegetables, and products for processing (industrial crops) (MADRP, 2016). The cereals, vegetable crops, and industrial crops productions reach 4.6 million tonnes, contributing 4% of national production. Tipaza also contributes with 6% of citrus production and 7% of vines (MADR, 2016). These types of crops are classified into three main areas according to the climate namely: The coast for an area of 4 200 ha for vegetable crops, the Mitidja for vegetable crops and arboriculture (21% of the SAU) covering 18 700 ha, and finally sheep, and cattle breeding in the mountain area (Mount Chenoua) with an area of 47 500 ha (Monographie/Tipaza, 2020).

The grazing area (pasture and grazing land) exceeds eight thousand hectares in the region. These areas are dedicated to sheep, cattle, and goats for the production of red meat, milk and dairy products, or wool, but also laying hens, broiler chickens and turkeys for the production of white meat and eggs.This production reached 19 200 quintals of red meat and more than 140 000 quintals of white meat in 2015 (MADR, 2016). The production of fodder is equally important as it constitutes the main source of livestock feed. In 2016, approximately 8 650 ha of fallow fields (mowed, grazed and natural grasslands) were exploited for the production of about 480 000 quintals of natural and artificial fodder, which corresponds to 1% of national production (ONS, 2016).

2.7.3.2. Forestry

Aleppo pine is the most common species in Tipaza, estimated at about 56% of the total forest area, followed by holm oak at 17% and cork oak at 7% in the western region (Conservation des Forêts/Tipaza, 2020). The forest-related operation in the wilaya of Tipaza include silvicultural work, forest plantations at a rate of 112, 20, and 97 ha respectively. In addition to ad hoc operations, such as trees cutting and removal following wildfires, which reached 707.88 ha in 2018. This sector also allows the region to enjoy various activities, such as beekeeping occupying more than 200 ha, or the planting of fruit trees.

The wilaya also has 11 classified forest projects or those in the process, with a total projected area of 177 ha in the municipalities of Hadjout, Sidi Ghiles, Sidi Amar, Damous, Hadjret Ennous, Tipaza, Chaiba, Bouharoun, Koléa, Ain Tagourait and Attatba (Monographie/Tipaza, 2020).

The production and processing of forest products can be summarized as follows: Timber (692 m^3), industry (25 m^3) and firewood (322 m^3), as well as more than 56 tonnes of other products, such as aromatic and medicinal plants, and cork (Monograph/Tipaza, 2020).

2.7.3.3. Fishing

The coastline of the wilaya of Tipaza extend between the municipality of Damous in the East and the municipality of Douaouda in the West at 123 km. This wilaya currently has five fishing ports, namely Gouraya, Cherchell, Tipaza (also a marina), Bouharoun and Khemisti (considered a fishing shelter). These ports shelter 866 fishing vessels, namely small-scale (546), sardine vessels (230), trawler (80), and tuna (10) (ONS, 2019), representing about 15% of the national fleet. With this fleet number the wilaya of Tipaza ranks at the top of the 14 coastal wilayas, where the largest number of vessels is held by Buharoun port.

This fleet land an average annual fish production of more than six thousand tonnes corresponding to 7% of the national average production (ONS, 2013; 2016; 2019). However, fishing in Tipaza has experienced a considerable decline estimated at 33% (2009-2019) similar to the national trend estimated at -11% (ONS, 2013; 2016; 2019).

Fishing is also practiced in the terrestrial lands in Tipaza, mainly at the level of the Boukerdane dam with a production of 3.8 tonnes in 2014. In addition to fishing, the aqua farming activity in the wilaya of Tipaza includes three companies, two of them are specialized in oyster farming with a production of approximately 532.6 tonnes in 2019 (DPRH Tipaza, 2020), and one fish farming company with a production of five tonnes in 2019 (DPRH Tipaza, 2020).

2.7.3.4. Tourism

The natural landscapes, the geographical situation bordering the Mediterranean, the historical and cultural heritage of the wilaya of Tipaza, give it undeniable assets favorable to the development of the tourist activity, which can contribute to the local economic growth of the wilaya. Indeed, along with its vast forests, numerous beaches with different morphologies, the wilaya account recognized and classified sites by international instruments, such the two archaeological parks of Roman ruins, covering 70 ha, classified by UNESCO as world heritage in 1982 (UNESCO, 2022).

In addition to these vestiges, the wilaya of Tipaza comprise tourism infrastructures to about 6 million visitors annually. This capacity is declined in various infrastructures, such as 42 hotels, 7 youth hostels (Damous, Gouraya, Cherchell, Hadjret Ennous, Ain Tagourait and Douaouda), ZET. Indeed, the wilaya has 22 ZETs with a total surface area of 1 950 ha, primarly located in the chief town of the wilaya, namely:

- The Tipaza-ZET of 87.5 ha, of which 29% belongs to the forestry domain and 43% to the agricultural domain intended to be reconverted into coastal management (Mohamed-Chérif and Lakhlef, 2013),
- The Matares ZET of about 157 ha, urbanized to 12% of the total area, including a tourist complex, a marine museum, a real estate cooperative and a future water treatment plant,
- The ZET of Chenoua, which covers more than 400 ha.

These expansion zones are programmed for development projects (completed in the case of the Tipaza-ZET) with the aim of increasing their reception capacity to 2 316 beds in 2019 and providing more activity for visitors by considering new tourist modalities such ecotourism (hiking).

2.7.3.5. Urbanization

Satellite imagery data and geomorphological studies show that the wilaya of Tipaza is a natural extension of Algiers' wilaya. Indeed, the geomorphological description of the wilaya of Algiers includes five main areas: the western sahel, with a topography showing an alternation between hills and plateaus, including the municipalities of western Algiers (Mahelma, Ain-Benian, Chéraga) and Mount Chenoua, which represents a geomorphological subdivision of the wilaya of Tipaza (Nouri & Ozer, 2014; Zerrouki & Belkadi, 2015).

Tipaza's wilaya host a population of more than 700 thousand inhabitants for a density average of 414 inhabitants/km² in 2019 against 346 inhabitants/km² at the last census of 2008 (Monographie/Tipaza, 2020). The most populated municipalities have more than 50 thousand inhabitants (Koléa, Fouka, Cherchell, Hadjout), showing a greater density of populations in the major urban centers of the Wilaya.

This is justified by the development of the municipalities of the wilaya to meet the needs of its population, particularly in the eastern region. The coastal area of the wilaya of Tipaza features a strong urbanization, mainly the development projects and the extensions that tend to advance towards the sea and which,with the exception of tourist centers, are not controlled (Nouri and Ozer, 2014).

The urban fabric of the wilaya is mainly represented by the real estate stock. It also includes supporting infrastructure, industrial areas and port facilities.

2.7.4. Urban fabric

2.7.4.1. *Dwellings and individual housses*

The real estate stock in the wilaya counted 167 493 dwellings in 2019, with an average TOL of 4.21 persons per dwelling. The municipalities of Koléa, Fouka, Cherchell, Hadjout and Bou-Ismaïl account for more than 40% of the stock. The least served municipalities are those of the West, in particular Hadjret-Ennous, Sidi- Semiane, Ain-Tagourait and Nador with less than 2500 dwellings per commune. Similarly, the largest municipalities (47% of the wilaya's territory) are associated with less than 15% of the wilaya's housing. The achievements of housing programs in the rural housing sector correspond to 56% the wilaya’s housing projects.

2.7.4.2. *Roads*

The road network of the wilaya of Tipaza comprise 1 713.6 km, with a road density of 1 km/km². This network includes 14% of national roads, 15% of wilaya roads, 66% of communal roads, 2% of dual carriageways and 4% of expressways. The wilaya has a total of 93 engineering structures of which 49% are in average or poor condition (Monographie/Tipaza, 2020).

2.7.4.3. *Port and airport works*

The territory of the wilaya of Tipaza does not include an airport. However, it comprises five main fishing and yachting ports, in addition to a commercial port of exchange by sea of a national and international scale (Port of El Hamdania in Cherchell). From West to East, the port of Gouraya occupying 4 ha, the port of Cherchell 2 ha, the port of Tipaza and the port of Bouharoun with 50 m² of solid land.

2.7.5. Waste management

The size and value of the agricultural, forestry and archaeological lands hinder the development of theindustrial sector in the wilaya, which has an insignificant industrial fabric except for a few industrial units whose effect on the environment is limited.

The wilaya has four technical landfill centers (LTC) for the treatment of DMA. These centers located in Sidi Rached, Attatba, Gouraya, and Hadjout. As regards to liquid waste with a total of 604 discharges were recorded in the wilaya, including 244 discharges from the coastal municipalities with a volume of 61 547 $m^3.day^{-1}$, which corresponds to 59.5 % of the overall flow of the Wilaya. This number of wastewaters is treated at the three treatment plants located in the municipalities of Hadjout, Chenoua and Koléa with a daily flow of 103 428 m.

CHAPTER 03. Methodology

The calculation of the EF of the two wilayas Algiers and Tipaza was built on data collected locally by the management entities of the various activities considered, namely fishing, food (crops and livestock), forestry, water, urbanization, and waste management. The component model combines urban metabolism analysis of the two wilayas UMA, with life cycle assessment LCA. This study also considered software application outputs, such as ArcGIS mapping for the aim of producing complementary data necessary for the calculation of the EF, in particular the energy and the land use statistics.

The scale of the study is based on the activity the wilayas under consideration residents. Therefore, the amount of data to be collected is larger and more detailed, considering all the components of an activity, compared to the original model, which focuses on final consumption by sector. Consequently, the first step in calculating the EF is the selection and the collection of data (inputs). This data includes first, the amount of material produced or consumed in each activity sector, second the energy use comprising both embodied (gray) energy (raw material extraction, manufacturing) or operational (maintenance and conditioning). And finally, the extent of land occupied by each activity (infrastructure).

The energy consumed for each activity is converted into the quantity of resulting emissions by using the LCA of the products manufactured or transported, of the fuels, of the energy consumed by households through the GEMIS (Global Emission Model for Integrated Systems) software.

3.1. Data collection

Information was gathered for each type of activity through discussions and working sessions with the organizations responsible for creating and disseminating this information using documentation defending the necessity for access to the information. The following table (**table 5**) lists for each activity the information required, the entity solicited for the acquisition of information, the structure, and the data quality (availability).

Table 5. Data collection caneva for the urban metabolism analysis of both wilayas

Sector	Component	Required data	Management Bodies		Observation	
			Algiers	Tipaza	Algiers	Tipaza
Fishing	Material	Fisheries landing statistics	MPPH[8] DPRH[9] Fisheries offices		Available data by port	
		Imported products	CNIS[10]		Available at the national level Unavailable at the wilaya level Unavailable for the considered year	
	Energy	Fleet number by type of métier	SGPP[11]		Available by port	
		Fuel consumption	Socio-economic survey		Incomplete, subject to uncertainties	
	Built land	Port infrastructures	Literature	DTP[12]	Available for the wilaya of Tipaza	
Food	Material	Crops production Livestock products	MADR[13] DSASI[14] DSA[15]		Available by wilaya ad by municipality in the case of the wilaya of Tipaza	
		National agriculture production Yield factors	FAO[16] (International data)		Available for at the national level	
		Crops area Pasture land	MADR DSASI		Available data	
		Imported crops	CNIS		Available. The information is difficult to read because of the coding used, as the national data use different codes than that of the FAO	
	Energy	Agricultural equipment Fuel consumption	BNEDER[17]		Analysis based on the agriculture share of total energy	

[8] Fishing and fisheries production ministry
[9] Directory of fishing and fisheries production
[10] National center for information and statistics
[11] Fishing ports management company
[12] Public works directory, maritime works department
[13] Ministry of agriculture and rural development
[14] Directorate of agricultural statistics and information systems
[15] Agricultural services directorate of the wilayas
[16] United nations food and agriculture organization, FAOSTAT
[17] National office for rural development studies

		during agricultural activity				
	Built land	Infrastructure related to agriculture suck as stocking and cooling	DSA Alger	DSA Tipaza	Number and capacity of storage facilities	
Forest	Material	Forest products	DGF[18]	Wilaya forest conservation and management	Aggregated data	Available at the wilaya level
		Forest areas				
	Built land	Storage area			Unavailable	
Urbanization	Material	Real estate stock Dwelling number Individual houses	MHUV[19] DL[20] DUAC[21] ArcGIS			
		Urbanized area	DUAC	DUAC		
		Area occupied by auxiliary infrastructure DEP	DEP[22] DPSB[23]		Data incomplete and unavailable in terms of surface area. The information is reported on the POS. However, these documents are not digitized and are available at the level of the municipalities	
	Energy	Energy used to manufacture building materials	GEMIS		Housing projects quantitative report	
		Residential electricity and natural gas	SONELGAZ[24]		Available and complete for Tipaza for households Unavailable for the wilaya of Algiers. Thus, extracted from the national energy report	
	Build area	Extent of the area occupiedby all	DUAC ArcGIS		Limited data. Assessed based on satellite imagery	

[18] General directorate of forests
[19] Ministry of housing, urbanism and urban planning
[20] Directorate of housing
[21] Directorate of architecture and urbanism
[22] public equipment directorate
[23] Budget monitoring department of the wilaya
[24] Algerian energy industrial group for production, distribution and marketing of electricity

		the infrastructures				
Urban waste	Material	Waste tonnage collected at the level of municipalities	EPIC NETCOM[25] EPIC EXTRANET[26]		Available	
		Waste tonnage treated at the landfill technical center	EPIC GECETAL	EPIC EPGW-TIPAZA[27]	Available	
	Energy	Fuel consumption during collection and transportation	EPIC EXTRANET	EPIC EPGW-TIPAZA	Incomplete data for fuel consumption by EPIC NETCOM equipment	Data unavailable and disaggregated at the commune level
		Energy consumption for waste management	EPIC GECETAL[28]		Approximate information based on an annual average for leachate treatment	Unavailable
	Built area	Area occupied by waste management infrastructure	EPIC GECETAL		Available	Incomplete, LTCs are described differently

3.2. Urban Metabolism and Life Cycle Assessment data

The structure of the UMA is key to structure the data and to provide output for the calculation of the EF. The UMA considers the two wilayas according to their administrative boundary, i.e., the absorption of carbon dioxide emissions estimated by GEMIS is assumed to be limited to the vegetation cover (forest) of each wilaya in isolation.

Moreover, the estimation of these emissions is a simple conversion based on emission factors generated by the GEMIS software, the principle of which is detailed in the appendices (**Appendix 3**). However, due to the specificity of each product and each sector of activity as well as the lack of data, the applications on this software have been preceded by calculations allowing to provide input data.

[25] Cleaning and household waste collection industrial and commercial establishment of Algiers
[26] Cleaning and household waste collection industrial and commercial establishment of Algiers
[27] Household and similar waste management company of Tipaza
[28] The company of the managment of Algiers Landfill Technical Centers

In addition to the individual tests, some of the conversion factors produced by LCA have been provided by the literature for some products such as plastic, metal and textile production industry. These conversion figures should be used with caution taking into consideration the limitations of the analysis, which is a major element in LCA studies. The following table details the conversion factors required for the different activities in the study (**table 6**).

Table 6. Source and method for emission factors calculation

Activity	Required data	Source of emissionfactor production	Study (author)
Fishing	Emissions associated With fuel consumption during the fishing trips	Modelled on GEMIS	[-]
Food	Emissions associated with fuel consumption during agricultural activities	Modelled on GEMIS	[-]
	Fertilizers	Literature	Makhlouf et al. (2019)
Urbanization	Energy-related emissions from the production of a dwelling made of concrete, brick and steel	Modelled on GEMIS	[-]
	Emissions associated with the use of electricity and natural gas		
Urban Waste	Manufacturing energy of products consumed by households including plastic, Metal, paper, glass, textile	Literature	Best Available Techniques of the European Commission (BAT[29])
			BAT 2013 a and b, 2015, 2017
			United States Environmental Protection Agency document (WARM[30])
			Data provided by experts[31] from similar studies
	Emissions associated with the energy consumed during waste transportation	Modelled on GEMIS	[-]
	Emissions associated with the LTCs energy consumption for MSW landfilling, and leachate treatment		

[29] Best available techniques
[30] Documentation for greenhouse gas emission and energy factors used in the waste reduction model
[31] Dr. Moore. School of Community and Regional Planning, University of British Columbia, Vancouver, Canada

3.2.1. Conversion figures

The GHG emissions resulting from energy consumption (embodied or operational) required using LCA for the production of conversion factors.

3.2.1.1. Fisheries sector (operational energy)

The following table (**table 7**) describes the fuel consumption by type of métier given in liters of diesel, and the resulting GHG emissions expressed in CO_2 equivalent (Mt CO_2eq). This analysis was based on two mainfigures:

First the fishing process: The energy generated from the combustion of one liter of fuel during fishing trips to produce one tonne of fisheries product.

Modeling this process was based on the lower heating value LHV of diesel given by the GEMIS software as 38.68 MJ. This figure allows the conversion of the given unit of volume into a unit of equivalent energy in joules (MJ).

Second the fishing effort: The total annual number of fishing trips obtained from the socio-economic survey.

For this amount of energy, the GEMIS software quantifies the CO_2 emitted by using as a conversion factor 0.407 Mt CO_2eq for 1 MJ of energy at 98% CO_2. The CO_2 emissions obtained for one tonne of fish products is then multiplied by the totalamount of landings tonnage of each wilaya.

Table 7. Estimated energy and GHG emissions associated with fishing

Wilaya	**Fleet per type of métier**	**Total fleet**	**Total fishing trips**	**Total landing**	**Fuel consumption** (L/tonne)	**Equivalent energy** (Mj/L)	**Resulting GHG emissions** (10^6 MtCO_2eq)
Algiers *Trawlers* *Sardine vessels* *Small-scae vessels*	51 81 143	**275**	1080	4 379.3	2 600.5	100 587	179.8
Tipaza *Trawlers* *Sardine vessels* *Small-scae vessels*	40 115 87	**242**	14 783	4 610	1 745	67 496.6	126.91

3.2.1.2. Food production sector (embodied energy)

The following tables (**tables 8, 9**) describe the types of fertilizer (market label name and chemical formula), the quantity used per type of crop, and also the energy factor in Gj and the emission factors expressed in tonnes of CO_2 eq, based on Makhlouf et al. (2019) analysis.

This study models the energy production in the fertilizer sector through an LCA. It also considers the extraction of basic elements nitrogen, phosphorus, and potassium, the different transformation processes as well as transportation to the storage plants. However, it is important to note that the fertilizers spreading on crop fields is accounted for in the operational energy category, which described fuel consumption per crop land categories. In the case of operational energy, which represent energy use by engines, the total consumption statistics were then converted into equivalent emissions using the LHV, assuming that all engines use diesel.

Table 8. Fertilizers production and the resulting GHGs in the wilaya of Algiers.

Product	**Type**	**Quantity**	**Energy**	**Total energy**	**Emission factor**	**Total emissions**
Market name	*Description*	*Tonne*	*Gj/tonne*	*Gj/year*	*Mt CO_2eq/tonne*	*Mt CO_2eq/year*
Urea	Nitrogenous fertilizer	4483.5	[-]	0	[-]	[-]
Urea (Sulfazote 26%)		113.3	20.4	2316.1	8.5	958.6
Ammonium Sulfate		9.2	[-]	0	[-]	0
Ammonium nitrate (Azofert N 21 %)		4.4	[-]	0	[-]	0
Calcium ammonium nitrate (CAN 27%N)		30.0	13.5	404.7	2.46	73.8
TSP (Triple Superphosphate)	Phosphorous fertilizers	29.1	13.2	383.0	1.11	32.3
SSP (Single superphosphate)		0.0	-0.3	0	0.78	0
Other		38.9		0	[-]	
Potas K2O (Potassium oxide)		139.1		0	0.72	100.16
Others		32.9		0	[-]	[-]
NP	Mixed fertilizers	54.2		0	[-]	[-]
NK		0.0		0	[-]	[-]
PK		1273.3		0	[-]	[-]
NPK (Sulfite-potassium based)		5936.0	11.3	67255.1	1.29	7657.5
Total fertilizers		**12 143.8**		**70 358.8**		**8 822.3**

Table 9. Fertilizers production and the resulting GHGs in the wilaya of Tipaza

Product	Type	Quantity	Energy	Total energy	Emission factor	Total emissions
Market name	*Description*	*Tonne*	*Gj/tonne*	*Gj/year*	*Mt CO_2eq/tonne*	*Mt CO_2eq/year*
Urea	Nitrogenous fertilizer	6 160	[-]	0	[-]	0
Urea (Sulfazote 26%)		15	20.4	304	8.46	126
Ammonium Sulfate		2	[-]	0	[-]	0
Ammonium nitrate (Azofert N 21 %)		5 400	[-]	0	[-]	0
Calcium ammonium nitrate (CAN 27%N)		7 214.3	13.5	97 393	2.46	17 747
TSP (Triple Superphosphate)	Phosphorous fertilizers	7 350	13.2	97 020	1.11	8 159
SSP (Single superphosphate)		0	-0.3	0	0.78	0
Other		13		0		
Potas K2O (Potassium oxide)		939	[-]	0	0.72	676
Others		5	[-]	0	[-]	0
NP	Mixed fertilizers	129	[-]	0	[-]	0
NK		0	[-]	0	[-]	0
PK		2 496	[-]	0	[-]	0
NPK (Sulfite-potassium based)		18 944	11.3	214 067	1.29	24 438
Total fertilizers		**48 666**		**408 784**		**51 145.3**

3.2.1.3. Water sector

The emission factors considered in this study are those associated with pipeline manufacturing. The water distribution network of the wilaya of Tipaza combines several types of pipelines: delivery, distribution, and desalination. Along its whole length, the distribution network comprises various materials, mainly steel with a diameter of 150 mm, iron with a diameter varying between 250 and 900 mm, PVC with a diameter of 100-200 mm, HDPE with a diameter of 60 to 300 mm and other materials.

In a conservation approach, this study assumes that the pipelines are HDPE, which is the material with the lowest CO_2 emissions according to the United Nations Environmental Protection Agency WARM document. Indeed, HDPE is associated with an emission factor of 0.39 Mt CO_2eq. Furthermore, based on the literature (norm 23.040.20 for plastic pipeline), the average weight of a smaller 63mm registered diameter pipeline is 3.8 kg/m. These figures have been used to calculate the embodied energy associated with the water distribution network (**Appendix 4**).

3.2.1.4. Urbanization sector

Prior to calculating the energy required to manufacture of building materials, the UMA was use to inventory the quantity of materials used in each wilaya by type of dwelling program, based on the real estate stock and the information provided by dwelling program reports.

This inventory is described in the appendices (**Appendix 4**). Consequently, the resulting emissions were modelled in GEMIS for one tonne of a "typical dwelling unite" which represent an average amount and weight of building material, i.e., concrete, bricks, and steel (**table 10**). The weight of the typical dwelling represents the sum of the weights of the three materials. The amount of GHG emissions obtained by the GEMIS model is multiplied by the total weight of each materials, then by the total number of dwellings in each wilaya.

Furthermore, the statistics of operational energy (electricity and natural gas) consumed by households in the two wilayas helped estimating the associated emissions on GEMIS using the conversion figures detailed in the appendices (**Appendix 4**).

Table 10. Emissions generated during the construction of the different types of housing

Dwelling programs and type	**Material proportion in a dwelling unit (%)**			**Dwelling weight (t)**	**GHG emission for 1 tonne of dwelling ($MtCO_2eq$)**
	Concrete	**Bricks**	**Steel**		
Rent-to-own (AADL)	36	23	41	46.3	$886.91*10^{-3}$
Participatory or urban support (LPP, LPA)	40	14	46	70	$949.10*10^{-3}$
« Typical dwelling »	38	18	43	58.8	$918*10^{-3}$
Individual houses	24.8	46	29.2	60.1	$735.39*10^{-3}$

3.2.1.5. Urban waste sector

The estimate of embodied energy consumed for waste management reflects the energy consumed upstream before the products consumption and dispose. Accordingly, two categories of products were defined based on field observations in the LTCs of the wilaya of Algiers and Tipaza, as well as statistics provided by GECETAL (wilaya of Algiers) and EPGW/Tipaza (wilaya of Tipaza). These two categories are as follows :

- Recycled materials: Those supposed to be manufactured by processes and from recycled materials. Therefore, emission factors of "recycling" type-manufacturing operations are assigned to these materials.
- Disposed (landfilled) materials: Those assumed to be manufactured by processes using raw material. Therefore, emission factors of "raw inputs" manufacturing operations are assigned to these materials.

The following table (**table 11**) details the emission factors extracted from the literature as decribed in section (**3.2**). These factors are described by category (recycled or landfilled) and by type of product, for the main products reported by the management entities of both two wilayas' LTCs.

Table 11. Emission factors of household and similar productsmanufacturing.

Product	Emission factors	Unit
Recycled materials		$MtCO_2eq$
Aluminum	2.12	
Steel	0.68	
Paper (divers)	0.73	
Newspaper	1.29	
Cardboard	0.89	
Printing paper	1.44	
PET	0.83	
HDPE	0.39	
PELD	1.54	
Landfilled materials		$MtCO_2eq$
Plastic	1.60	
Diapers	3.58	
Paper and cardboard	1.14	
Textil	20.8	
Metal	2.60	
Glass	0.55	

3.3. Ecological footprint and biocapacity assessment

3.3.1. Calculation of the ecological footprint for each category of activity

The resulting data from the UMA and the LCA represent input data required for the calculation of the EF. The calculation is based on a conversion equation using conversion factors (YF, EQF), estimating the equivalent area to produce fisheries products, crops, livestock, forest products, and absorb the waste generated from energy use (manufacturing, transportation), and the required land for infrastructure.

It is worth noting that each activity and product is associated with specific conversion factors. The conversion factors, namely the YF and EQF, provided annually by the GFN for each country, summarized in the appendices (**Appendix 2**).

3.3.2. Calculation of biocapacity

The biocapacity BC, which defines the natural capital of each wilaya, is estimated from the statistics describing the different categories of lands. This study considers the following areas: Fishing areas, agricultural land (SAU), forest areas, and urbanized land.

The statistics used for this calculation are those provided by the management entities mentioned above, in addition to the data obtained from the processing of satellite images on ArcGIS, in particular the exploited fishing areas in the two wilayas, and the urbanized land described in the appendices (**Appendix 5**). The calculation of the BC is also based on specific conversion factors for each land use category (**Appendix 2**).

CHAPTER 04. Results and discussion

4.1. Urban metabolism inventory

It is important to state that the EF assessment inputs have been generated from urban metabolism analysis combined with life cycle assessment (LCA). In this section data inventory is detailed for both wilayas, i.e., Algiers and Tipaza. The generated inventory for some sectors lacks data. These cases are mainly related to the unavailability of some statistics (ND).

For all the sectors, the statistics obtained are structured in conformity with the EF framework by components, namely:

- Material: including the products consumed, produced, or even generated for each sector of activity in both wilayas. This component then converses in the equivalent EF of production (e.g., EF_crops)
- Energy use: comprising the three main forms of energy used in Algeria: fossil fuel, natural gas, and electricity. This component then converses in the equivalent EF carbon dioxide generated from energy (EF_carbon)
- Land use: represented by the infrastructure associated with each activity (EF_builtland)

4.1.1. Fishing sector

The following tables (**tables 12, 13**) describe the share of the fishing sector in the urban metabolism in the wilaya of Algiers and Tipaza for 2015.

For the energy component, the embodied energy in fishing represents the energy required for ship manufacture. This component has been considered only in the wilaya of Tipaza for the shipbuilding and repair company ECOREP, in terms of electricity use and gasoil consumption.

The operational energy for the functioning of the fishing activity considers the fleet's fuel consumption and the electricity use in the fisheries. Moreover, for the wilaya of Tipaza, the calculation of the EF associated with energy includes the aqua farming energy use.

Table 12. Fishing sector share in Algiers' urban metabolism (2015)

Component	Required information	Data	Unit
Material	Fisheries total landings	3 695.7	tonnes
	Fisheries landing by species categories Small pelagic Large pelagic Demersal fishes Crustaceans Molluscs	 3320.4 42.51 209.34 101.9 21.52	
Energy	**Embodied energy in fishing**		
	Embodied energy in aqua farming (fish meal)	ND	
	Operational energy		
	Electricity consumption by port activities	27 030	KWh
	Total fuel consumption during fishing trips	11.4	10^6 Liters
	Fuel consumption by vessel type Trawlers	 7.1	10^6 Liters

	Sardine vessels Small scale vessels	1.8 2.5	
	Energy consumption for aqua farming (electricity)	ND	KWh
Built Land	Ports infrastructures Port of El Djamila Port of Alger Port of Tamentfoust	189.7 2.7 184 3	Hectares

Table 13. Fishing sector share in Tipaza's urban metabolism (2015)

Component	Required information	Data	Unit
Material	*Fisheries total landings*	9 023.9	Tonnes
	Fisheries landing by species categories Small pelagic Large pelagic Demersal fishes Crustaceans Molluscs Others	 425.54 8 163.9 144.13 75.28 142 73	
Energy	Aqua farming product Fish Mediterranean Mussel Oyster	990 600 290 100	Tonnes
	Embodied energy in aqua farming (fish meal)	ND	
	Embodied energy in marine fishing activity Fuel consumption (ECOREP) Electricity consumption (ECOREP)	 23 095.5 12 416	 Liters KWh
	Operational energy		
	Electricity consumption by port activities	ND	KWh
	Fuel consumption by vessel type Trawlers Sardine vessels Small scale vessels	1.7 0.71 0.9 0.30	10^6 Litre
	Energy consumption for aqua farming (electricity)	10 000	KWh
Built Land	Total ports infrastructure	16.4	Hectares
	Port of Gouraya Port of Cherchell Port of Tipaza Port of Bouharoun Port of Khmisti	4 2 5.6 0.005 4.7	
Other surfaces	Total aqua farming infrastucture (marine surface) Shellfish farming Fish farming	0.20 0.18 0.2	

4.1.2. Food sector

This sector includes agricultural products (**Appendix 7**) and livestock products (meat and derived products). The number of storage facilities was extracted from a census of agriculture operators (**Appendix 5**). These structures, described in terms of storage capacity in m^3, are converted into a surface area (ha) assuming an average height of five meters (**tables 14, 15**).

Table 14. Food sector's share in Algiers' urban metabolism (2015)

Component	Required information	Data	Unit
Material	Total crops production	393	10^3 tonnes
	Cereals (durum wheat, and spring wheat)	5.13	
	Industrial crops	0	
	Dry vegetables	0	
	Vegetable crops	199	
	Citrus	98.7	
	Vineyards	29.4	
	Fruit trees	0.3	
	Total production of poultry meat	70 47.1	
	Other livestock products		10^6 Liters
	Milk	14.03	
	Total livestock	38 833	Heads
	Buffaloes	521	
	Cattle	14429	
	Goats	3614	
	Horses	879	
	Sheep	193390	
Energy	**Embodied energy (Fertilizers)**		
	Total amount of used fertilizers	12	10^3 tonnes
	Production energy	70 358.8	GJ
	Operational energy (Fuel consumed during farming)		
	Agriculture vehicles and equipment	4 438	Unites
	Total fuel consumption by equipment	12.79	10^6 Liters
	fuel consumption by copping categories		
	Field crops[32]	0.5	
	Industrial crops	-	
	Vegetable crops	7	
	Fruit trees	5.51	
Built Land	Storage facilities	380	Unites
	Estimated surfaces occupied by storage facilities (5m high)	2.83	Hectares

[32] Agricultural crop cultivated on a large area such as wheat, corn, soybean

Table 15. Food sector's share in Tipaza's urban metabolism (2015)

Component	Required information	Data	Unit
Material	Total crops production	982	10^3 tonnes
	Cereals (durum wheat, and spring wheat)	60	
	Industrial crops	16.7	
	Dry vegetables	0.8	
	Vegetable crops	396	
	Citrus	103	
	Vineyards	340.4	
	Fruit trees	65.5	
	Total production of poultry meat	114	
	Other livestock products		
	Milk	36.5	
	Eggs	197	
	Honey	325	
	Wool	130	
	Total livestock	65 879	Heads
	Buffaloes	885	
	Cattle	10 815	
	Goats	6037	
	Horses	872	
	Sheep	47270	
Energy	**Embodied energy (Fertilizers)**		
	Total amount of used fertilizers	48	10^3 tonnes
	Production energy	51 145.3	GJ
	Operational energy (Fuel consumed during farming)		
	Agriculture vehicles and equipment	12 143	Unites
	Total fuel consumption by equipment	17.27	10^6 Liters
	fuel consumption by copping categories		
	Field crops[33]	3.47	
	Industrial crops	0.16	
	Vegetable crops	7.17	
	Fruit trees	6.46	
Built Land	*Total storage facilities*	290	Unites
	Cooling rooms	287	
	Silo and flat-bottomed sheds	3	
	Cooling rooms	3.07	Hectares
	Silo and flat-bottomed sheds	3	

4.1.3. Forest sector

This sector is mainly considered for estimating forest area extent required to supply forest products such as timber and wood. However, the collected data does not describe forest activities, the engines used, or the energy consumed. The latter is disaggregated into multiple levels. Therefore, **table 16** describes only the material components for both wilayas.

[33] Agricultural crop grown on a large area such as wheat, corn, soyebean

Table 16. Forest product in Algiers and Tipaza (2015)

Component	Required information	Data		Unite
		Algiers	Tipaza	
Material	Cork production	0	0	Tonnes
	Aromatic plants	ND	1	
	Timber	15.5	350	m^3
	Industrial wood	668.7	2.4	
	Wood for heating	307.5	12.5	
	Construction wood	215.2	[-]	
	Charcoal	3	[-]	

4.1.4. Water sector

This sector considers the water production capacity in both wilayas and the residents' consumption. It also accounts for the operational energy used for water pumping and distribution and the embodied energy consumed to manufacture the distribution network's pipelines. However, the embodied energy associated with the water sector was estimated only for 100km in Tipaza, as the network's length is not described in the collected data. Moreover, statistics that describe the pipeline features (material, diameter) in the wilaya of Algiers are also unavailable (**tables 17, 18**). Therefore, the calculation of the embodied energy of the distribution network (pipeline) follows a conservative approach, described in (**Appendix 4**).

Table 17. Water sector's share in Algiers' urban metabolism (2015)

Component	Required information	Data	Unit
Material	Water capacity mobilized	1.2	10^6 m^3/day
	Water supply from dams	297	Hm^3
	Daily supply of drinking water	165	Liters.day^{-1}. Capita^{-1}
Energy	**Embodied energy associated with the pipeline manufacture**		
	Length of the water distribution network	4 510	Km
	Manufacturing energy		
Built land	*Number of dams supplying the wilaya of Algiers*	7	Unites
	Surface of the dams supplying the wilaya of Algiers Keddara Hamiz Koudiat Acerdoune Douerra Taksebt Souk Tleta Bouroumi	ND	

Table 18. Water sector's share in Tipaza's urban metabolism (2015)

Component	Required information	Data	Unit
Material	Water capacity mobilized	169 064	10^6 m^3/day
	Water supply from dams	105.2	Hm^3
	Daily supply of drinking water	220	Liters.day^{-1}. $Capita^{-1}$
Energy	**Embodied energy associated with the pipeline manufacture**		
	Length of the water distribution network	100	km
	Manufacturing energy	148.2	$MtCO_2eq$
Built land	Number of dams supplying the wilaya of Algiers	2	Unites
	Total surface of dams Boukerdane Meurad	-	Ha

4.1.5. Urbanization sector

This sector includes residential dwellings and individual houses. The material component refers to the quantity of building materials. The operational energy component is the energy needed for heating and cooling (e.g., electricity), and the embodied energy is used to manufacture building materials (**Appendix 4**). Two methods estimate the built area: an estimate based on the number of houses (**Appendix 5**) and an estimate based on satellite imagery (ArcGIS). The second method includes, besides the residential areas, all the infrastructure of the two wilayas (**tables 19, 20**).

Table 19. Residential urbanization sector's share in Algiers' urban metabolism (2015)

Component	Required information	Data	Unit
Material	Total housing inventory Dwellings (1999-2015)	3 532 431 3 094 132	Unites
	Individual houses	602 247	Unites
Energy	**Embodied energy**		
	Building materials Concrete Brick Steel (concrete bar)	 39.1 2.1 2.3	10^6 tonne
	Building materials energy Concrete Brick Steel (concrete bar)	60 35.9 14.2 9.84	10^6 $MtCO_2eq$
	Operational energy		
	Electricity consumption Clients (Residential) Total electricity consumption Resulting CO_2 emissions	1 939 896 2148.06 0.81	Clients GWh 10^6 tCO_2

	Natural GasClients (Residential) Total natural gas consumption Resulting CO_2 emissions	525 112 743.2 6.17	Clients 10^6 m^3 tCO_2
Built Land	Total area of dwelling and houses Dwellings (60m²) Individual houses (100m²)	7 879 1 856 6 022.5	Hectares

Table 20. Residential urbanization sector's share in Tipaza's urban metabolism (2015)

Component	Requied information	Data	Unit
Material	*Total housing inventory* Dwellings (1999-2015) Individual houses	153 356 151 961 1 395	Unites
Energy	**Embodied energy**		
	Building materials quantity Concrete Brick Steel (concrete bar)	2.2 1.88 0.16 0.16	10^6 tonnes
	Building materials energy Concrete Brick Steel (concrete bar)	0.6 0.46 0.58 0.084	10^6 $MtCO_2eq$
	Operational energy		
	Electricity consumption Clients (Residential) Total electricity consumption Resulting CO_2 emissions	 525 112 636.23 0.27	 Clients GWh 10^6 tCO_2
	Natural Gas consumption Clients (Residential) Total natural gas consumption Resulting CO_2 emissions	 61 965 77.3 0.65	 Clients 10^6 m^3 tCO_2
Built Land	*Total area of dwelling and houses* Dwellings (60m²) Individual houses (100m²)	105 91 14	Hectare

4.1.6. Urban waste Sector

This sector involves the management of municipal household solid waste (MSW) and liquid waste (urban wastewater UW) combined under the category of urban waste. It should be noted that water discharges are included in this sector, although it is managed by the water management company (SEEAL).

Therefore, the material component refers to the amount of waste collected at the level of the municipalities of both wilayas at the landfill technical centers (LTC) and the wastewater treatment plants (WTP) (**tables 21, 22**). The energy component includes, first, the operational energy, such as fuel consumed during the transport and treatment of waste. Then, the embodied energy consumed in the manufacture of products consumed by households and recovered in the LTCs. The built area component includes the infrastructure related to waste treatment.

Table 21. Urban waste's share in Algiers urban metabolism (2015)

Component	Required information	Data	Unit
Material	Total MSW	1. 01	10^6 tonne
	UW Landfills leachate	0.29 97.35	10^6 m^3
Energy	**Embodied energy in consumable products' manufacture**		$MtCO_2eq$
	Recycled Material Aluminum Steel Paper (other) Newspaper Cardboard Print paper PET HDEP	 1391.8 38.5 95.8 19.1 0.3 249.2 949.2 39.8	$MtCO_2eq$
	Landfilled Material Plastic Dippers Paper and Cardboard Textil Metal materials Glass	14.4 0.17 4 0.8 1.04 0.26 0.11	10^6 $MtCo_2eq$
	Operational energy		
	Total vehicules and engins for MSW collection and landfilling	425	Unites
	Solid waste treatment energy		
	MSW collection and transportation MSW landfilling	53 0.012	10^6 liters
	Liquid waste treatment energy		
	Leachate treatment UW treatment	0.26 13.8	GWh
Built land	*Total area for waste management* LTCs Leachate treatment plants UW treatment plants	240 58 21.25 161	Hectares

Table 22. Urban waste's share in Tipaza's urban metabolism (2015)

Component	Required information	Data	Unit
Material	Total MSW	158.1	10^6 tonne
	UW Landfills leachate	8.3	10^6 m^3
Energy	**Embodied energy in consumable products' manufacture**		$MtCO_2eq$

	Recycled Material Aluminum Steel Paper (other) Newspaper Cardboard Print paper PET HDEP	 0 419.8 0 0 39.7 0 559.9 111.1	$MtCO_2eq$
	Landfilled Material Plastic Dippers Paper and Cardboard Textil Metal materials Glass	 28 470 62 634.2 12 622 16 4494 4 112.4 1 752.4	10^6 $MtCO_2eq$
	Operational energy		
	Total vehicules and engins for MSW collection and landfilling	13	Unites
	Solid waste treatment energy		
	MSW collection and transportation MSW landfilling	0.4 0.26	10^6 liters
	Liquid waste treatment energy		
	Leachate treatment UW treatment	0 0.8	GWh
Built land	*Total area for waste management* LTCs Leachate treatment plants UW treatment plants	41.9 31.9 0 10	Hectares

4.2. Inventory of the ecological footprint analysis

The estimation of the EF was based on data from the UMA. Calculation results are described in the following tables by sector for both wilaya. Moreover, EF by species (fishing sector) and crops (food sector) are detailed in the appendices (**Appendix 6, 7**).

4.2.1. Fisheries sector

In the case of fisheries, the EFs for fishery products are based on quantifying the primary production required by PPR, expressing each species' food requirement. The PPR considers energy and biomass transfer between predator species and their prey (assuming a linear relationship) and the trophic level of each species. The EF considers a total of 90 products from all fishery product categories, namely demersal fish, small and large pelagic fishes, crustaceans, and mollusks.

Moreover, the fishing EF considers energy and artificialized areas. The results are described in **table 23** and figure **5**.

Table 23. Fishing Sector's Ecological Footprint in the wilaya of Algiers and Tipaza

Component	Data		Unit	Emission (tCO_2eq)		Ecological Footprint (*gha*)	
	Algiers	Tipaza		Algiers	Tipaza	Algiers	Tipaza
Material	3695.7	9 023.9	Tonnes	[-]	[-]	15338.48	275030.43
Embodied Energy	[-]	12 416	KWh	[-]	65.9	11950.9	1496.55
	[-]	23 095.5	Liters	[-]	4.71		
Operational Energy	35 030	[-]	KWh				
	11.4	1.7	10^6 Liters	35 894.95	4422.15		
Total energy		[-]	[-]	35 849.95	4496.61		
Built Land	189.7	16.4	Ha			176.88	15.29

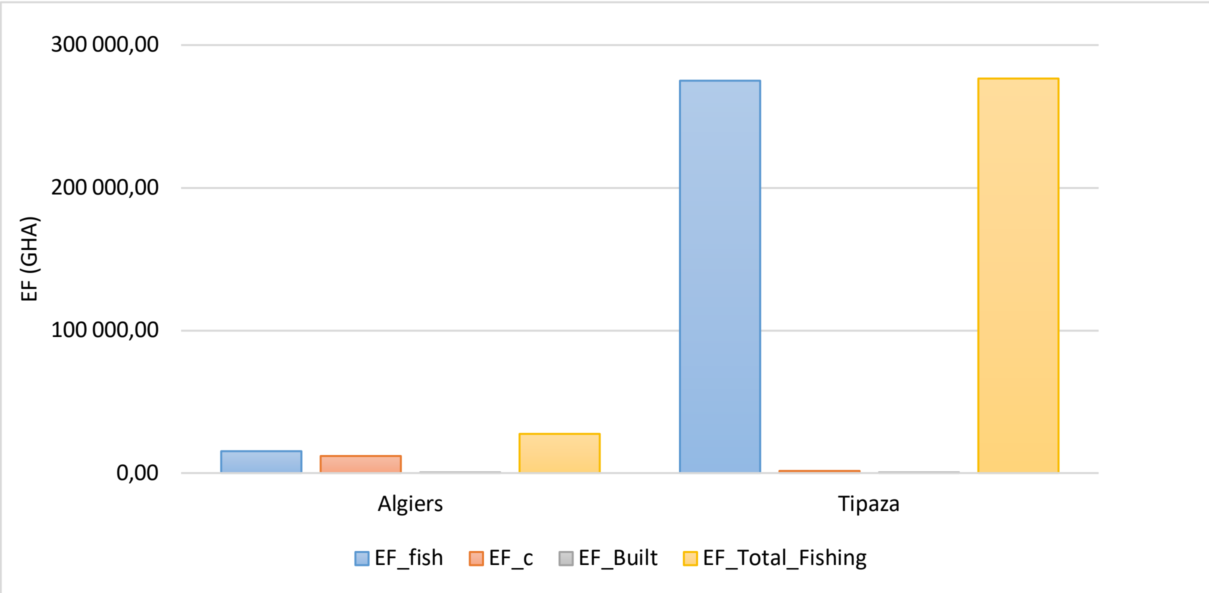

Figure 5. Ecological footprint of the fishing sector of Algiers and Tipaza wilayas (2015)

The fishing EF of Tipaza is 17 times that of Algiers, as the wilaya of Tipaza's total landing is twice that of Algiers. The fisheries of both wilayas target the same species, particularly small pelagics and demersal fish, with an average trophic level of 3.85. Consequently, the large gap in EF_fish relates mainly to the tonnage of species caught, which is higher in Tipaza.

According to the study results, the EF_fish accounts for most of the EF_Total_Fishing in both wilayas (99% in the wilaya of Tipaza). This could be related to the absence of data describing energy use in this sector, as it was mostly limited to fuel consumption during fishing.

The PPR depends on two variables: the trophic level TL and the fishery production tonnage. It should be noted that the TL depends on species identification by the data collectors at the port during the landing, which could be challenging. As a matter of fact, fisheries landing statistics describe species by their common names or even those used locally. This annotation makes the selection of the corresponding trophic level complex. Indeed, this is the case for several species, such as *Sarpa salpa* (saupe, chelba, tchelba), *Dasyatis pastinaca* (tchouch, pastenague), and *Trachurus trachurus* (Chinchard, saurel). In addition, other species are reported under the corresponding category, such as mollusks, small pelagic, and demersal fish. In this case, selecting an average trophic level by category could bias the PPR, thus the EF_fish results.

The EF_c, expresses the required land to sequester CO_2 emissions generated by energy (fuel combustion). This metric is associated with the combustion of gasoil during fishing for three main métiers categories: trawlers, sardines, and small-scale vessels. The latter is eight times higher in Algiers compared to Tipaza. Trawlers consume the highest amount of fuel.

Moreover, a detailed study highlighted that sardine vessels use the least fuel quantity per estimated production compared to trawlers and small-scale vessels, representing 67% and 23%, respectively. This could be related to the significant tonnage of pelagic fishes that sardine vessels land since small pelagic fishes represent more than 80% of Algeria's fisheries. The study context could also explain these findings. Indeed, thus CO_2 emissions estimates are based on information provided by fishers, such as fishing trips number per month for each type of métier and gasoline consumption during fishing trips.

Moreover, the emissions resulting from fishing trips represent about 90% of the total emissions of the fishing sector. Consequently, the management bodies (e.g., DPRH, SGPP) and the fishers should pay further attention to this component.

However, other parameters have not been considered, particularly the embodied energy exploited for shipbuilding, aquaculture's fish meal, and fisheries products processing.

The EF_built in Algiers is greater mainly due to the greater extent of port structures in Algiers.

4.2.2. Food sector

Detailed EF by crops and livestock products, is detailed in **Appendix 7** for both wilayas. This calculation is based on conversion figures (yield factor, equivalence factor) specific to each product and each category of land (cropland and grazing land). Moreover, the EF equivalent to livestock product is estimated according to the NFA basis for grazing land footprint (**Appendix 2**).

Table 24. Ecological Footprint of the Food sector of Algiers and Tipaza' wilayas (2015)

Component	Category	Data		Unit	Emissions (tCO_2eq)		Ecological Footprint (gha)	
		Algiers	Tipaza		Algiers	Tipaza	Algiers	Tipaza
Material	Crops	396.1	820.9	10^3 Tonnes			$8.1*10^5$	$1.0*10^6$

	Livestock	38833	65879	Head[34]			$1.3*10^4$	$1.5*10^4$
Operational Energy	Fuel consumption	421.8	298.6	Liters	34153.5	45492.9	$1.1*10^4$	$1.5*10^4$
Embodied Energy	Fertilizers	12	48	10^3 Tonnes	$8.82*10^3$	$1.77*10^4$	$2.9*10^3$	$5.9*10^3$
Total Energy					42975.8	63239.9	$1.4*10^4$	$2.1*10^4$
Built land		2.83	17.27	Ha			2.63	16.1

The calculation results are described in the table above (**table 24**) and figure **6**. The EF of the material is named EF_crops and EF_pasture, the energy is EF_energy, the built land is referred to as EF_built, and the total footprint of food is EF_Total_food.

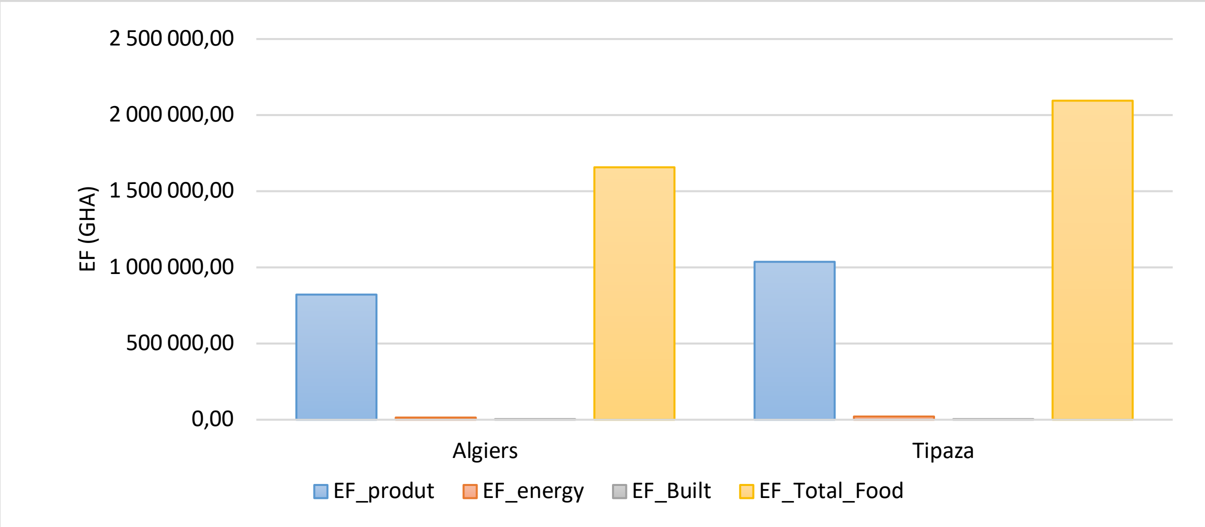

Figure 6. Ecological footprint of the food sector of Algiers and Tipaza wilayas (2015)

In line with its agropastoral domain, the wilaya of Tipaza requires more than one million hectares of hypothetical surface for its agricultural activity, represented at 99% by the crops. This is 19 times larger than that of the wilaya of Algiers, as the wilaya of Tipaza's crop production is twice that of Algiers. The two wilayas share a similar production of livestock.

The most harvested products are not necessarily associated with high EFs, as their EF depends mainly on their YF, which is a function of the average world yield of a specific year. The EF of orange is the highest in Tipaza. The surface dedicated to the plantation of orange is one of the most important in the region, corresponding to approximately 8% of the total agricultural surface of the wilaya. With durum wheat, clementines, cauliflower, olive oil, grapes, peaches, potatoes, onions, and tomatoes, it covers 57% of the EF_crops. Moreover, the EF of some products, such as dry peas (9 tonnes, 64 gha), lentils (40 tonnes, 33gha), corn, cherries, and peanuts, has an insignificant contribution to the total EF_crops of the wilaya of Tipaza because the wilaya does not produce or produces small quantities compared to its overall annual production.

[34] The EF of livestock products calculation considered livestock counts instead of production in tonnes of meat.

The EF_crops of the wilaya of Algiers is 0.8 million gha. The latter follows the same trend as Tipaza, with few exceptions. The products: oranges, cauliflowers, peaches, grapes, green cabbage, apples, green beans, turnips, potatoes, carrots, green beans, lemons, and clementines represent 90% of the EF of the wilaya. For both wilayas, some products have a high national yield exceeding the average annual world yield, such as chili peppers, eggplants, and pears, which could be justified by the availability of varieties of some products that are not available worldwide.

For the same component (material), the EF was calculated for livestock products EF_pasture. In this case, despite data describing the tonnage of the products (e.g., red meat, milk, honey), the associated data (e.g., livestock average daily feed, market supply) is unavailable. Therefore, EF-pasture estimates are based on livestock statistics by the head (cattle, sheep, goats, and horses) using the calculation matrix provided by the GFN (2014). Accordingly, the detailed calculation is detailed in (**Appendix 2**). The associated EF_pasture accounts for less than 1 to 2% of the total EF_Total_Food of both wilayas. The wilaya of Tipaza's EF_pasture is almost twice that of Algiers due to the highest number of sheep and goats (**Appendix 2**). This also related low EF associated with farm animals, such as the "poultry" category, compared to the "cattle" category, which holds more than 60% of the EF-pasture.

The EF_c is twice as important in Tipaza. The latter includes the embodied energy resulting from the use of fertilizers for cropping and the operational energy in terms of fuel consumption by type of harvest. The embodied energy is associated with more than 2 900 gha in the wilaya of Algiers and twice as much in Tipaza (5 906.51 gha). This finding is related to the high crop production in the wilaya of Tipaza and the larger production areas.

In comparison, the EF of the operational energy of the two wilayas is of the same order, ranging from 11 to 15 thousand gha. This result is not plausible, as the wilaya of Tipaza has more than 7 000 operational agricultural machines, which is expected to result in systematically higher energy consumption associated with a higher EF_c. However, the estimate of CO_2 emissions and EF_c is based on a simulation of fuel consumption as a function of cropping land surfaces. The latter is extracted from the Ministry of energy's report on agricultural activity's share of the total energy use. Indeed, this could be irrelevant to assessing agricultural activities' impact and does not provide adequate information to identify which crop is the most energy-intensive.

The EF_ built in the wilaya of Tipaza is six times more important. This may reflect the number of infrastructure in the wilaya of Tipaza or the availability of statistics describing these infrastructures. Furthermore, the estimate of physical surfaces only accounts for the cooling storage facilities of the two wilayas and the storage silos of the wilaya of Tipaza, which may lead to an underestimation of the built EF.

4.2.3. Forest sector

The estimation of the EF of forestry is limited to assessing the demand for forest area to produce forest products (timber, wood). The conversion figures used to convert a quantity of forest product to equivalent EF are YF=1.82 m3/ha for charcoal and construction wood and timber (Total Industrial Wood) and YF=3.35 for fuelwood. Moreover, according to the NFA, all products are allocated an EQF of 1.92gha/ha (GFN, 2014). The EF by forest product in the two wilayas is resumed in the following table (**table 25**) and figure 7.

Table 25. Ecological footprint of the forest sector in Algiers and Tipaza (2015)

Component	Category	Data		Unit	Emissions (***tCO₂eq***) (gha)	
		Algiers	Tipaza		Algiers	Tipaza
Material	Cork production	0	0	tonnes	[-]	[-]
	Aromatic plants	ND	1		[-]	
	Total Industrial Wood	991.7	364.9	m^3	2 328.3	856.7
	Firewood	215.2	0		930.0	[-]
	Charcoal	3	0		7.0	[-]
	Total				3 265.3	856.7

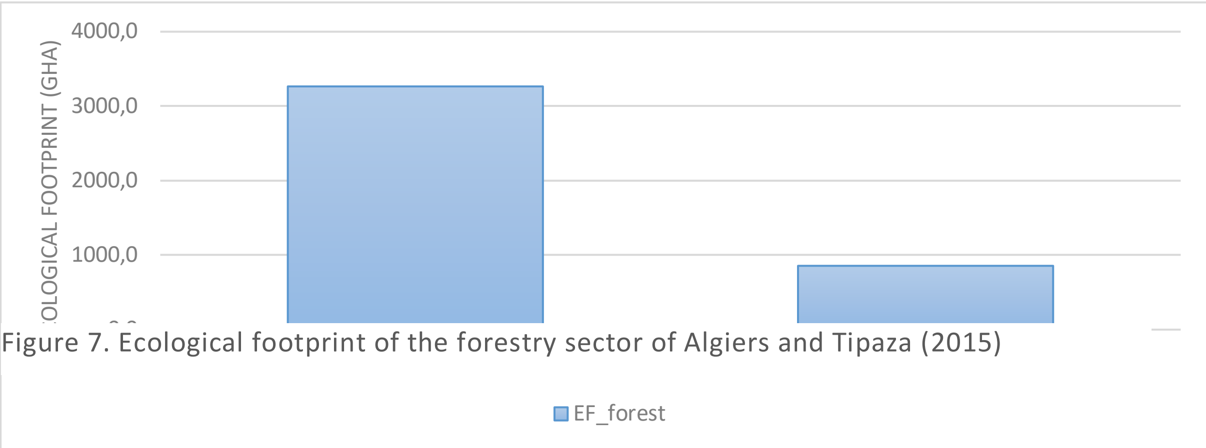

Figure 7. Ecological footprint of the forestry sector of Algiers and Tipaza (2015)

The EF associated with forestry in the two wilayas consists exclusively of the material component due to the absence of data describing the other components (energy and built area). The EF_wood of the wilaya of Algiers is significantly higher than that of Tipaza. This is related to the information available and the number of forest products industries, which is higher in Algiers. The statistics of the wilaya of Tipaza report the production of one tonne of aromatic product. The EF equivalent to this production has not been calculated due to the absence of a conversion factor corresponding to this product (YF) in the matrix EF_Forest (forest products) and EF_crops (agricultural products).

4.2.4. Water sector

The national ecological footprint accounts (original model) do not convert the volume of water produced into the equivalent production area. Thus, this category considers the energy associated with water distribution in two forms:

- The energy embodied in the construction of water collection and distribution structures (dam and pipeline)

– The operational energy of water's distribution (energy consumed during pumping and water transfer).

Although the wilaya of Algiers' statistics do not describe the material that constitutes the pipe of the water distribution network, the EF of the embodied energy was calculated, assuming that this material is HDPE (lower emission factor).

The operational energy for water production and the transfer was provided by the SEEAL/Tipaza for the year 2020 (production = 11.4 GWh, transfer = 22.5 KWh) for more than 20 million m^3 (produced) and 34 million (transferred). This data was included to model the energy consumed for one m^3 of drinking water and define the equivalent EF_c.

The EF of the built area is associated with the area occupied by water capture infrastructures, i.e., artificial water dams, including the Koudiate Acerdounedam in Algiers and the Meurad dam in Tipaza. The calculation results of the EF_c and EF_built are described in the table **26** and figures **8** and **9**.

Table 26. Ecological footprint of the water production sector in Algiers and Tipaza wilayas

Component	**Category**	**Data**		**Unit**	**Emissions (*tCO_2eq*)**		**Ecological Footprint (gha)**	
		Algiers	**Tipaza**		**Algiers**	**Tipaza**	**Algiers**	**Tipaza**
Material		1.2	48.2	m^3				
Operational Energy	Production	[-]	0.57	kWh/m^3	[-]	10 422.5	[-]	3 468.8
	Transfer	[-]	0.66		[-]	8 550.2	[-]	2 845.7
Embodied Energy	Pipeline	4510	100	km	6683.8	1 480.2	2 224.5	49.3
Total Energy					6683.8	19120.9	2 224.5	6 363.8
Built land		ND	ND	km^2				

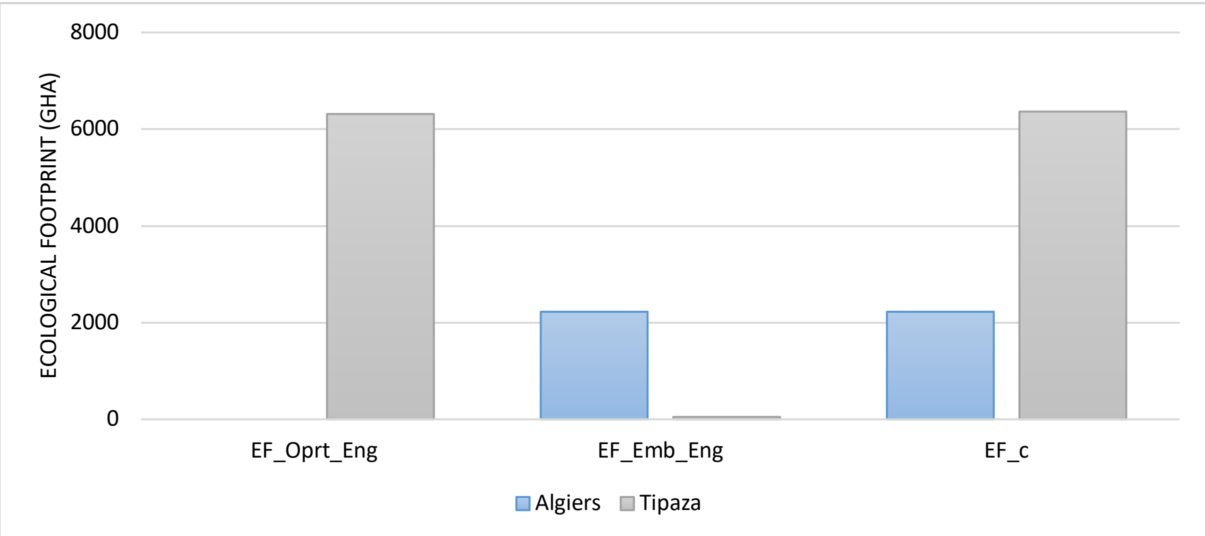

Figure 8. Operational and embodied energy's share in total EF of both wilayas

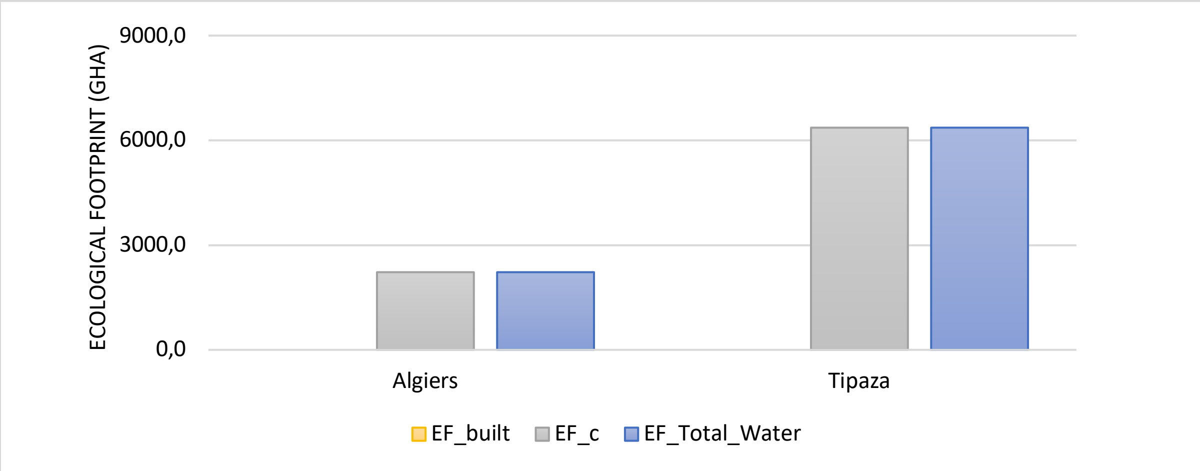

Figure 9. Ecological footprint of the water production sector in Algiers and Tipaza wilayas.

The wilaya of Tipaza's EF associated with the energy use for water production and distribution exceeds that of Algiers by more than 1000 gha. This gap could be related to the unavailability in Algiers' case, especially in describing the operational energy of water production and transfer.

However, this result is consistent with the water capacity of the wilaya of Tipaza, which is represented by significant water production compared to the wilaya of Algiers. Moreover, the daily supply is higher in Tipaza, supplied by water production sources such as the Boukerdane Dam (Sidi Ammar) and the Fouka desalination plant (Fouka) with 240 000m^3/day. These sources are both wilayas (Monographie/Alger, 2016). Indeed, the wilaya of Algiers is supplied by dams located beyond its administrative boundaries. Nonetheless, according to the EF methodology, the energy required to transfer this quantity of water, the resulting GHG emissions, and equivalent GHG sequestration EF are computed in the budget of the wilaya (Algiers). This assessment enables defining the demand of the wilaya of Algiers on neighboring wilayas. According to the results obtained, the emissions generated by the operational energy constitute the bulk of the EF_c in Tipaza, including more than 55% of the energy dedicated to production. It is worth noting that the embodied energy is poorly described in both wilayas. Consequently, the calculation relies on the assumption that the water network including distribution, pumping and desalination pipelines is made of the least polluting material i.e., HDEP (0.39MtCO_2eq/tonne). Nevertheless, these estimates still require accurate descriptions (e.g., pipeline lifespan), which are likely to provide different outputs.

The EF_built describes the EF equivalent to the artificial surfaces for water dam of the two wilayas that have essentially natural dams.

4.2.5. Urbanization sector

The EF of urbanism resumes the estimation of the surface required for absorbing GHG emissions associated with the construction of dwellings and the EF of the residential maintenance and conditioning energy, and the EF of the surface occupied by the real estate stock.

The results of the estimation of the EF_c, the EF_built and the EF_total_urbanism which represents the sum of the two types of EF are described in the tables 27 and 28 for the wilaya of Algiers and the wilaya of Tipaza, respectively (**figures 10,11**).

Table 27. Ecological footprint of the urbanization sector in the wilaya of Algiers (2015)

Component	Required information	Data	Unit	Emission (tCO_2eq)	Ecological footprint (*gha*)
Material	Dwellings	2602.7	10^3 units		
	Individual houses	602.2			
Operational energy	Naturel Gas	743	$10^6 m^3$	6.17	2.5
	Electricity	2148.1	GWh	$8.10*10^5$	$2.70*10^5$
Embodied energy	Concrete	40.9	10^6 Tonnes	$3.59*10^7$	$1.20*10^7$
	Bricks	18.8		$1.42*10^7$	$4.72*10^6$
	Steel	12.8		$9.84*10^6$	$3.28*10^6$
Total energy				$6.08*10^7$	$2.02*10^7$
Built land	Dwelling's built area	1561.61	ha		$1.46*10^3$
	Individual houses' built area	6.02			5.92
	Total residential area				1567.63

Table 28. Ecological footprint of the urbanization sector in the wilaya of Tipaza (2015)

Component	Required information	Data	Unit	Emission (tCO_2eq)	Ecological footprint (*gha*)
Material	Dwellings	152	10^3 units		
	Individual houses	1.4			
Operational energy	Naturel Gas	77.3	$10^6 m^3$	$6.5*10^{-1}$	$2.16*10^{-1}$
	Electricity	718.2	GWh	$2.70*10^5$	$8.99*10^4$
Embodied energy	Concrete	1.9	10^6 Tonnes	$4.63*10^5$	$1.54*10^5$
	Bricks	1.9		$5.83*10^4$	$1.94*10^4$
	Steel	0.1		$4.96*10^4$	$1.65*10^4$
Total energy				$8.41*10^5$	$2.8*10^5$
Built land	Dwelling's built area	91.2	ha		$8.96*10^1$
	Individual houses' built area	0.01			$1.37*10^{-2}$
	Total residential area	1567.63			$1.54*10^3$

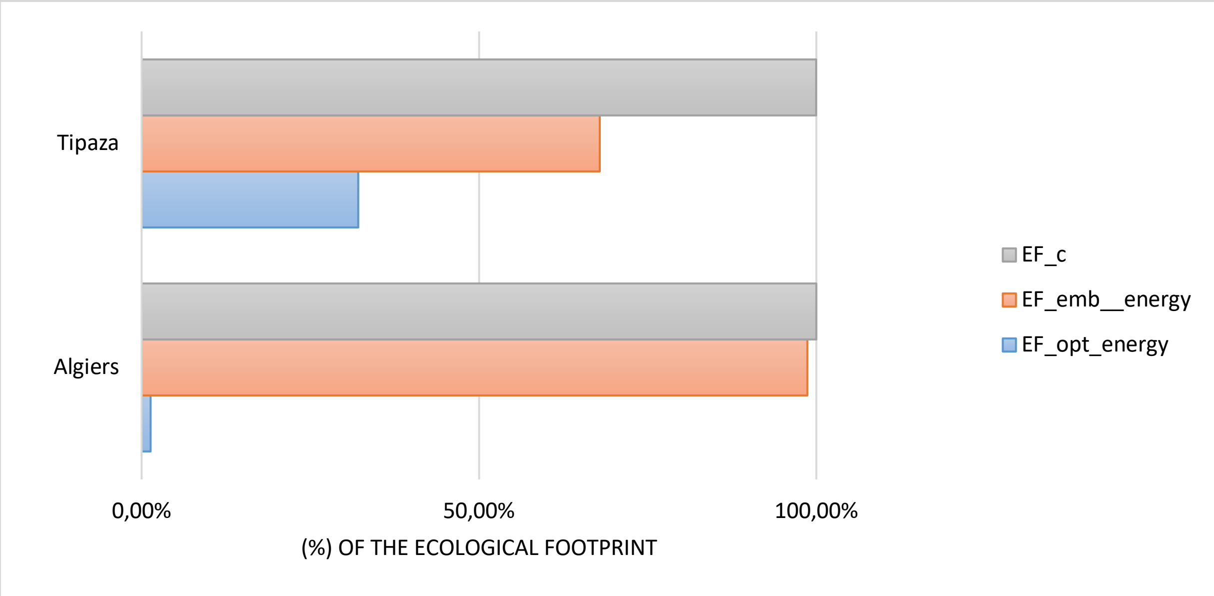

Figure 10. Operational and embodied energy proportion in the Total Energy Ecological Footprint of urbanization

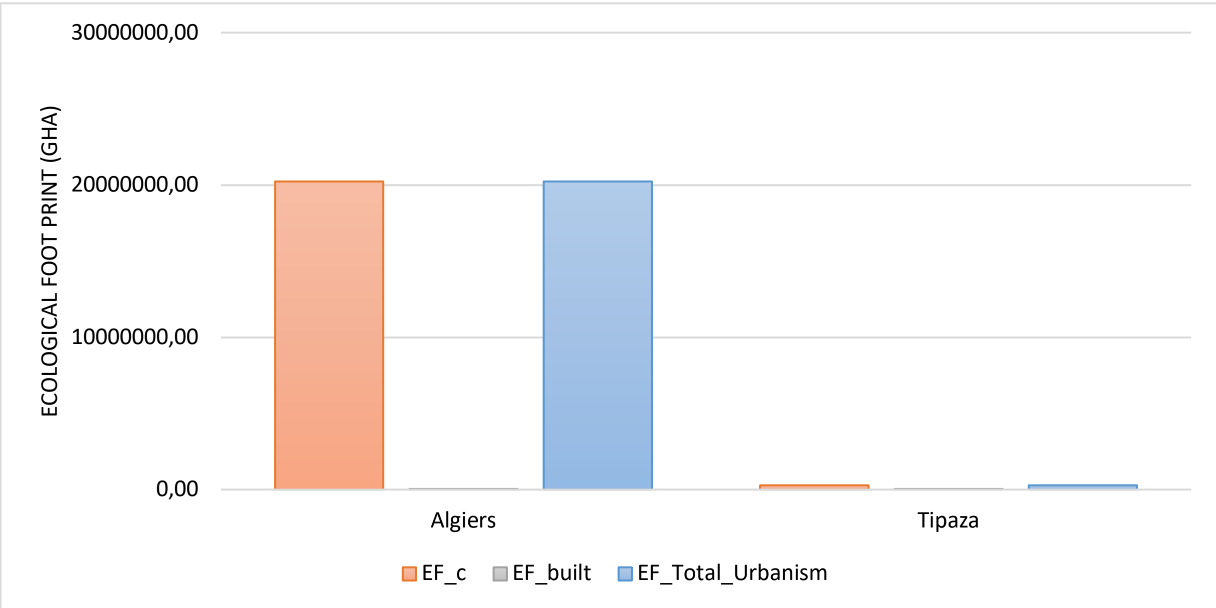

Figure 11. Ecological footprint of the urbanization sector of Algiers and Tipaza wilayas

On an area twice as small as that of the wilaya of Tipaza, the wilaya of Algiers is home to a population of 3.15 million in 2015. This population is settled in more than 3.5 million housing units consisting of about 80% dwellings and 20% of individual houses (self-build). Proportionally to these figures, the EF of the wilaya of Algiers EF_urbanism is 72 times larger than that of the wilaya of Tipaza.

The EF_Total_ Urbanism is represented at 99% by the EF of energy associated with the manufacture of building materials, i.e., the EF_emb_energy (98% in Algiers and 67% in Tipaza), and to a lesser extent the conditioning energy (1.33% in Algiers and 32.1% in Tipaza). Indeed, EF_opt_energy of the two wilayas is based on the emissions resulting from the combustion of natural gas, which are about 10^3 kg for 1 MJ of gas burned. In addition, the emissions associated with the generation and natural gas distribution to final users are negligible. Similarly, the consumption of electricity has a low impact on the energy EF because the emissions associated with this energy are mainly a result of the processing of natural gas and roughly 10^3 kg/MJ.

The estimate of EF_emb_energy is based on both wilayas' real estate stock, and the proportion of the mostly used construction materials. In the case of this study, only concrete, brick and steel (concrete reinforcing bars) were considered and their proportions were approximated using the specifications of some residential projects and individual house construction.

Therefore, the EF_emb_energy is dependent on the quantity of these materials and the size of the total housing stock of the two wilayas. It is worth noting the building materials' origin, transportation patterns, the auxiliary materials as well as the construction techniques has not been considered. Consequently, it is likely that the availability of such information would affect the calculation. It could thus be an overestimate or an underestimate of the emissions associated with the production of the three materials.

In both wilayas, the EF_c of dwellings is more important than that of individual houses. This is mainly due to the number of this kind of habitation which is lower than that of the dwelling projects. Indeed, at the scale of one unit, the construction of a single-family house (based on quantitative reports) can generate more CO_2 emissions and require a larger than dwellings. However, these results should not be considered separately from the quality, origin and manufacturing processes of the building materials.

The EF_built of the wilaya of Algiers is proportional to the number of dwellings and thus more important compared to the wilaya of Tipaza. Indeed, figures **12** and **13** below, reveal that the surface of the wilaya of Algiers is more than 32% urbanized compared to a low percentage of 12% in the wilaya of Tipaza, which has been increasing for both cities to reach about 45% for the wilaya of Algiers and double the size for the wilaya of Tipaza (30%). The expansion of urbanization differs between both wilayas. Though, the comparison betwwen the 2015 and 2022 (**figures 14, 15**) state outlines that the human expansion in both wilayas converge, covering the western municipalities of Algiers (Zéralda) and the Eastern municipalities of Tipaza (Koléa), which share the same boundaries.

However, the EF calculation, in this study- considers only the surface occupied by residential buildings, thus, the interpretation doesn't account for all the infrastructures comprised in the "urban land" in each land occupation map (e.g., roads).

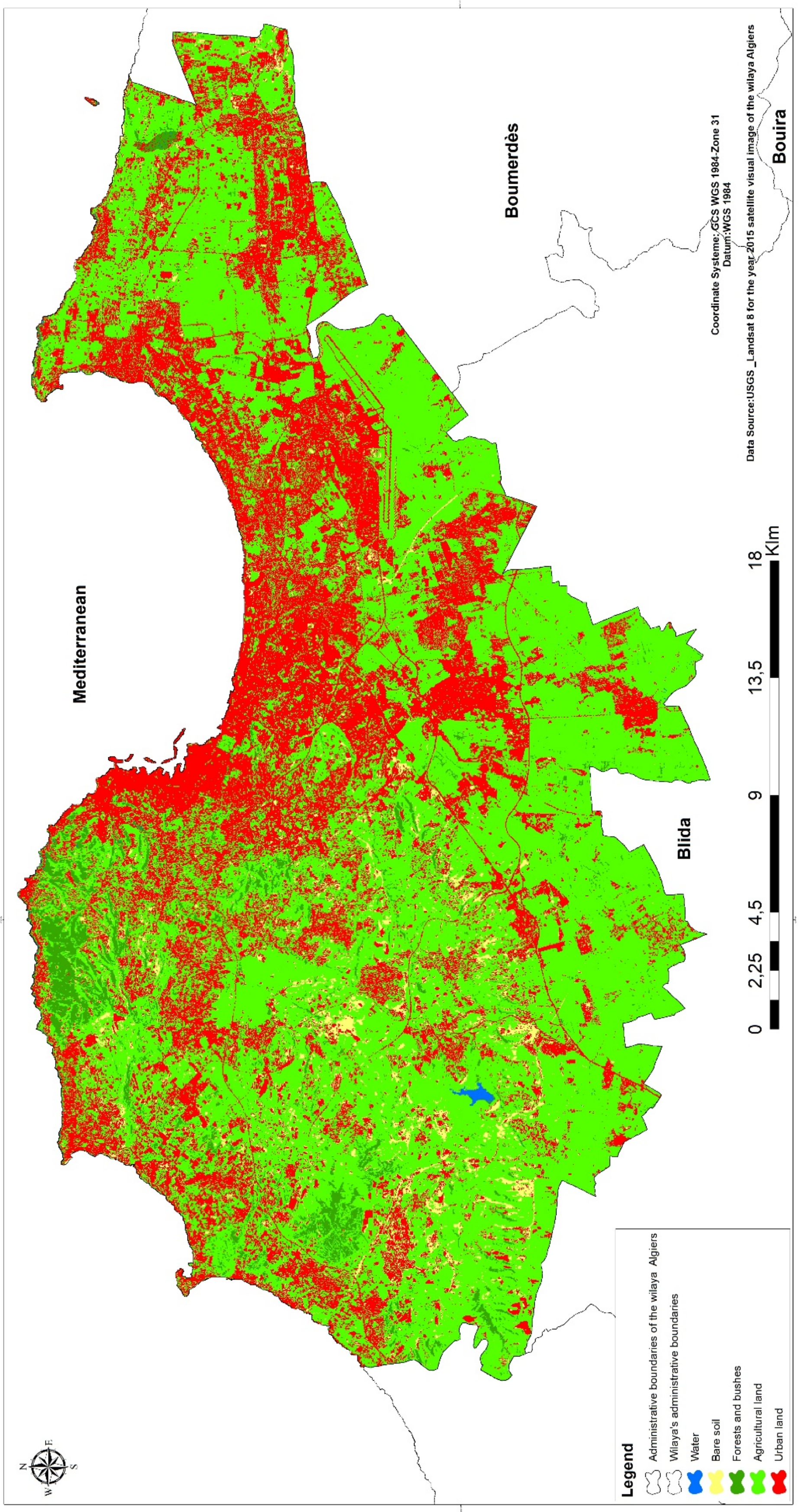

Figure 12. Land occupation map in the wilaya of Algiers in 2015

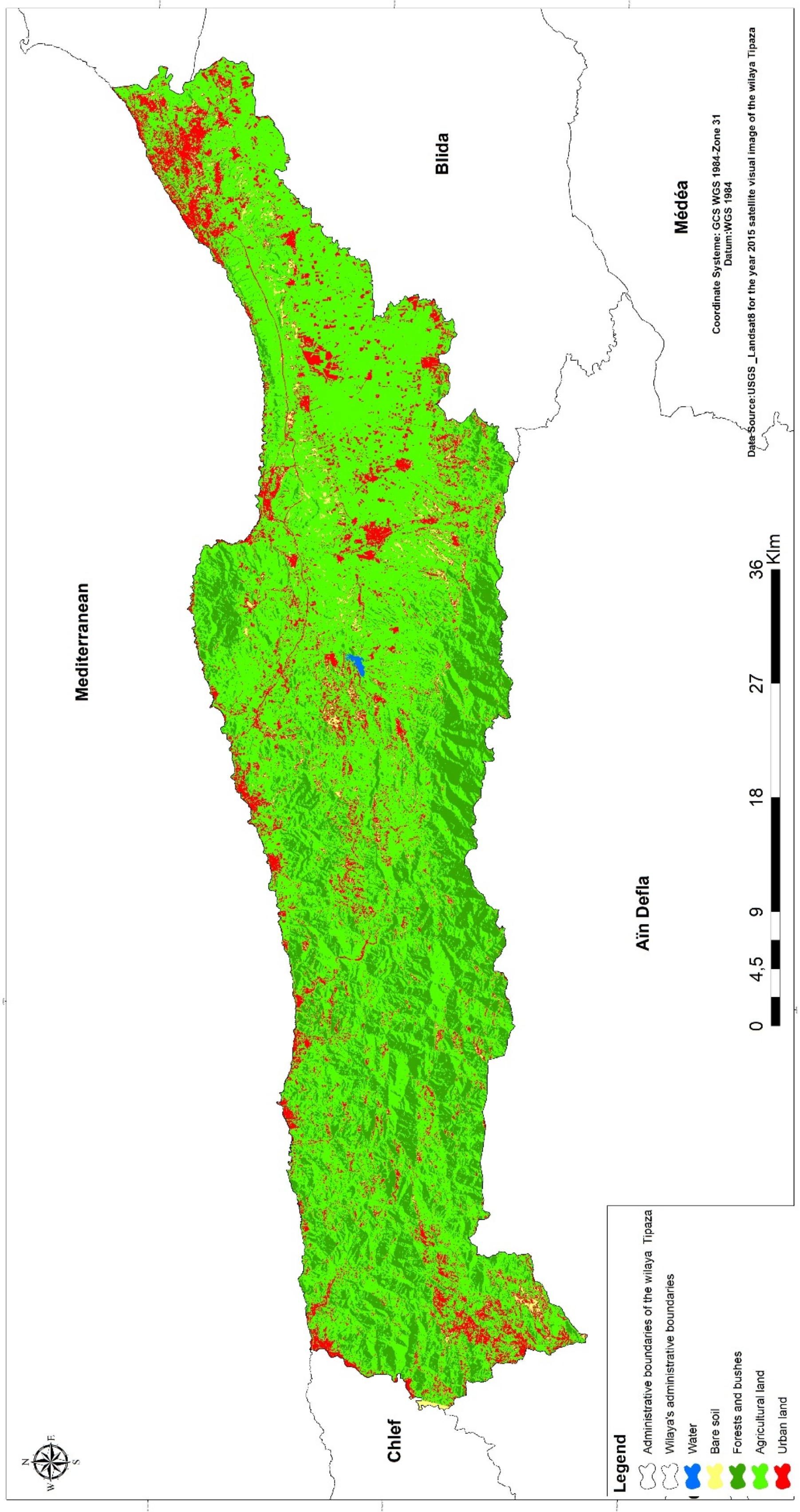

Figure 13. Land occupation map in the wilaya of Tipaza in 2015

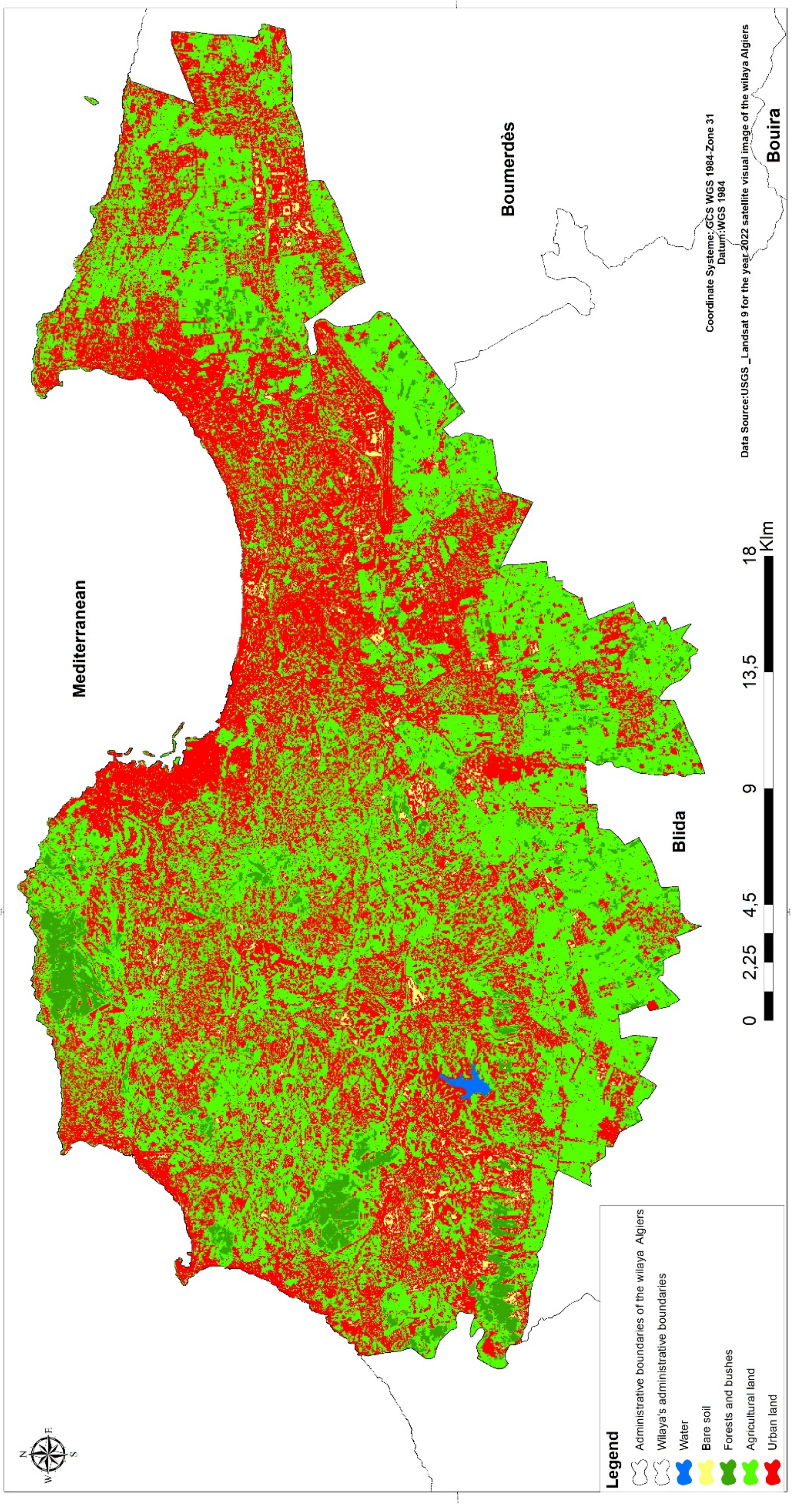

Figure 14. Land occupation map in the wilaya of Algiers in 2022

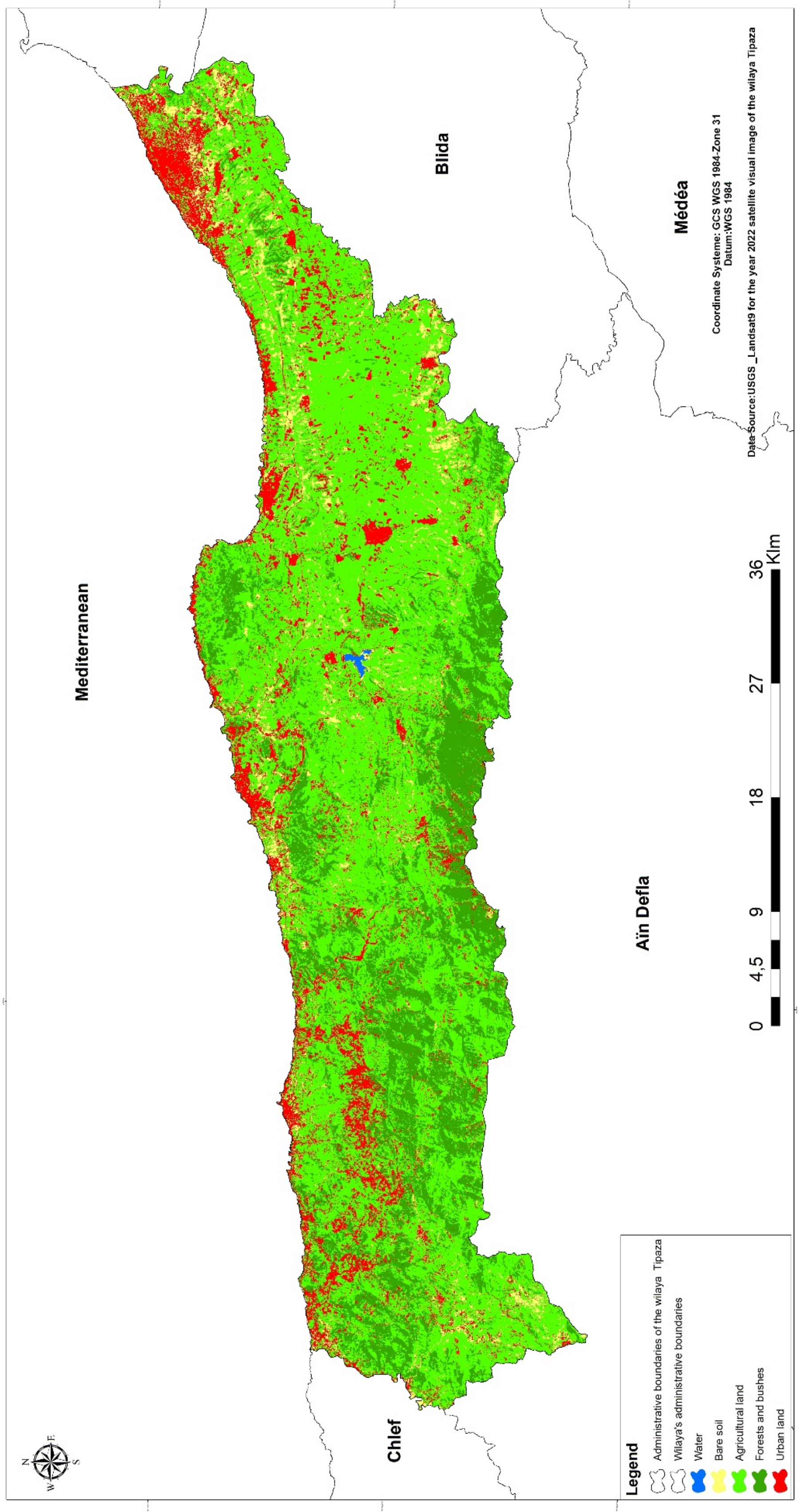

Figure 15. Land occupation map in the wilaya of Tipaza in 2022

4.2.6. Urban waste sector

The EF of waste management expresses the surface area required to sequester the GHG emissions resulting from the manufacture of consumable products upstream of their consumption and their deposit at the level of the LTCs or their recycling. This is based on the tonnage of these products and their basic materials, i.e., Plastic (PET, HDPE, and PP); metal (steel, aluminum), paper (cardboard, newsprint).

The EF of the energy of maintenance and conditioning is that consumed in the activities of transportation and treatment of the various forms of waste (solid waste, liquid waste). Finally, the area occupied by the landfills and the wastewater plants is used to estimate the EF_built.

The results of the estimation of the EF_c, the EF_built and the EF_Total_Waste which represents the sum of the two types of EF of the wilaya of Algiers and the wilaya of Tipaza are described by the **tables 29** and **30**.

Table 29. Ecological footprint of the urban waste sector of the wilaya of Algiers (2015)

Component	Required information	Data	Unit	Emission (tCO_2eq)	Ecological footprint (gha)
Material	Disposed MSW	1 005 141	Tonnes		
	Recycled MSW	1997.05			
Operational energy	MSW transportation	5 296 834.35	Liters	15662.6	5212.8
	MSW landfilling	1 283 400		4869.8	1620.8
	Leachate treatment	0.26	GWh	98.7	32.9
	UW treatment	13.8		5239.3	1743.7
	Total			25870.4	8610.1
Embodied energy	Disposed MSW manufacture			1440943.7	479571.3
	Recycled MSW manufacture			1391.8	463.2
	Total			1442335.5	480034.5
Total energy				1468205.9	488644.7
Built land	LTC surface	32	ha		29.8
	UW plant	64			59.67

Table 30. Ecological footprint of the urban waste sector of the wilaya of Tipaza (2015)

Component	Required information	Data	Unit	Emission (*tCO_2eq*)	Ecological footprint (gha)
Material	Disposed MSW	158 167	Tonnes		158 167
	Recycled MSW	540.5			540.5
Operational energy	MSW transportation	336015.1	Liters m^3	2504.5	336015.1
	MSW landfilling	262.8		777.1	262.8
	Leachate treatment	[-]	GWh	[-]	[-]
	UW treatment	0.78		698.8	0.78
	Total			3 980.4	1 324.7
Embodied energy	Disposed MSW manufacture				274084.61
	Recycled MSW manufacture			1391.8	1130.5
	Total			1442335.5	275 215.1
Total energy				279 195.5	
Built land	LTC surface	32	ha		32
	UW plant	10			10

Figures **16** and **17** outlines EF calculation results and a clear comparison between the wilayas of Algiers and Tipaza in terms of total ecological footprint associated with the waste management sector and energy forms.

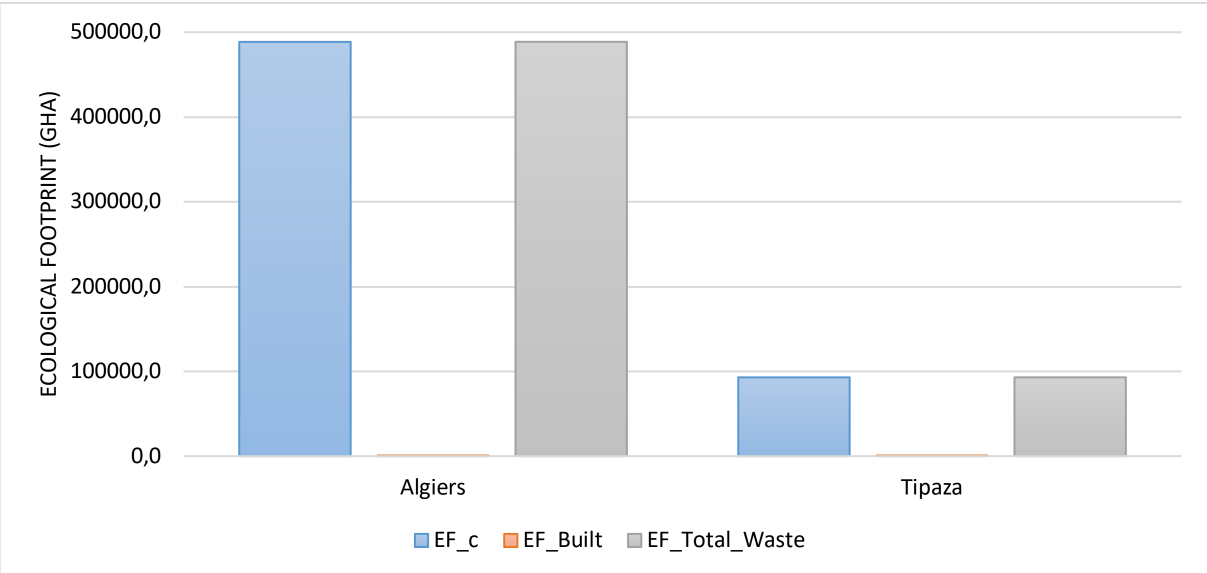

Figure 16. Ecological footprint of the urban waste sector of Algiers and Tipaza wilays

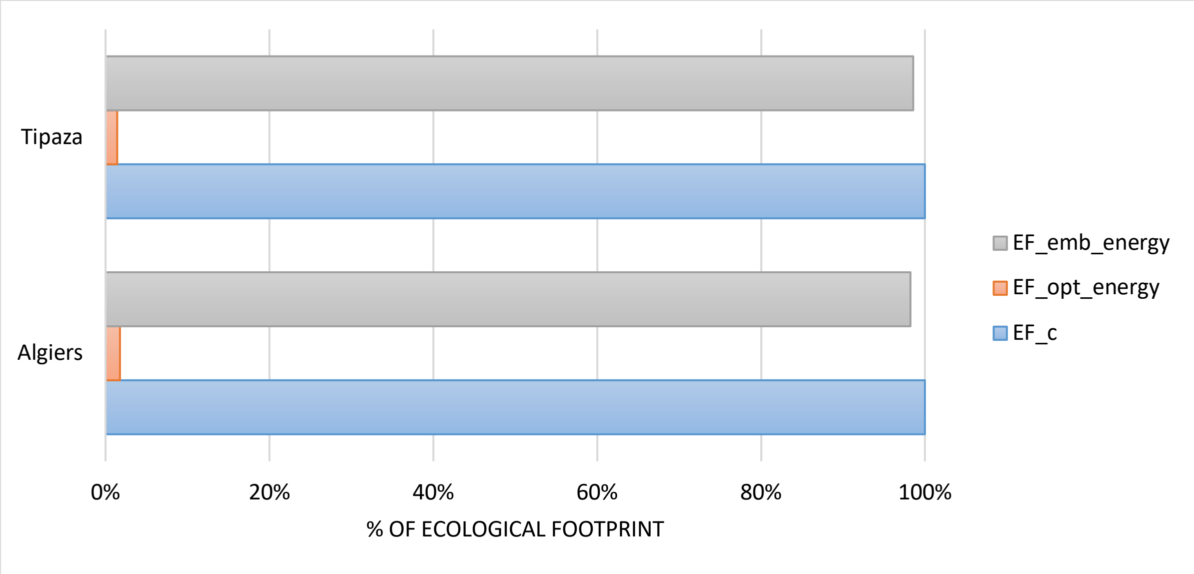

Figure 17. Operational and Embodied energy share in the total energy's Ecological Footprint of the urban waste sector of Algiers and Tipaza (2015)

Although the wilaya of Algiers is twice smaller than that of the Tipaza, it hosts more than 3 million inhabitants in 57 municipalities, four times higher than the wilaya of Tipaza. Moreover, along with its large population, the wilaya of Algiers generates more solid waste and urban wastewater, thus, using more energy for MSW collection, transportation, landfilling and UW treatment. Consequently, GHG emissions are higher in the wilaya of Algiers than in Tipaza, leading to an EF_Total_Waste seven times larger in the wilaya of Algiers.

For both cases, waste generation is coherent with population growth. Tipaza's annual waste generation rate equals 0.58 kg per capita per day. Municipalities such as Kolea, Fouka, Hadjout, Cherchell, Tipaza, and Bou Ismail have the largest records in Tipaza (**Appendix 9**). These communes account for 58 percent of total MSW, consistent with the regions' high population and expanding urbanization. In Algiers, that rate equals 0.86 kg per capita per day Municipalities with the most significant records are Les Eucalyptus, Borj El-Kiffan, Gue de Constantine, Borj El-Bahri, and Baraki, representing 23% of total MSW (**Appendix 9**).

It is complex to define the exact production origin of materials in consumer goods. Nevertheless, the results indicate that the materials consumed in Algiers are associated with higher emissions. The majority of waste ends in landfills. Indeed, aside from plastic PET, which is the most recycled product, diverted waste is negligible in both cases due to data shortage. However, it could be argued that accurate data is expected to increase the total EF of waste transportation and treatment, especially in the wilaya of Tipaza, which lacks data regarding waste transportation.

The landfilled materials in the two wilayas represent more than 99% of the waste tonnage collected. The emissions generated by the manufacture of consumables (which become waste after use) were estimated on the basis of the emission factors of one tonne of each type of product (landfilled product or recycled product). The EF associated with the manufacture of products is systematically more important in the wilaya of Algiers, as it depends on the tonnage. In addition, the landfilled waste category is assumed to be manufactured from raw material. This accounts for 99% of the energy EF in both wilayas. However, the absence of selective sorting of waste by type of material at the municipal level prior to the collection process could weakens the estimation the materials quantity included in the residents' consumer goods, and the potentially of the recoverable waste.

Based on field observations, in both wilayas, MSW tonnage is underestimated for further reasons: waste removal from dumping containers, and substantial amounts of waste on the shore that cannot be collected due to the difficulty of accessing these areas by truck. In addition, the observed overflow of waste in cities, especially from dumping bins, confirms a disparity in waste collection frequency and efforts.

The volume of urban wastewater generated in wilaya Algiers is 12 times higher than in the wilaya of Tipaza. This significant volume requires higher energy consumption. Accordingly, the EF_opt_energy in Algiers's wilaya is higher, including leachate treatment.

Regarding operational energy, MSW transportation accounts for more than 50% of CO_2 emissions in the two wilayas and requires the most considerable EF. However, fuel consumption data was complex and could have led to an underestimation. For instance, in the wilaya of Algiers, only data from EXTRANET were complete and included in the estimated associated GHG emissions, assuming that this organization covers large parts of Algiers' municipalities (EXTRANET, 2019). Nevertheless, despite this limitation, EF_c associated with fuel usage remains the largest among waste management operations.

Indeed, data shortages are a recurrent issue, especially in Tipaza, because individual municipalities are still partly responsible for waste collection. Thus, information regarding the operating fleet is disaggregated and challenging to obtain. Similarly, the data structure is not standardized, and waste management differs in both cities in several aspects (Akrour et al., 2021).

Onsite observations have revealed that LTCs of the region under consideration are designed differently. Even though landfilling has been one of the oldest waste treatment options, LTC architecture in the two cities has many shortcomings. For example, Tipaza LTCs lack leachate treatment stations, and only one of the three LTCs is equipped with a sorting shed. EF_built is proportional to the extent of infrastructures for waste management. Therefore, it is relatively significant in the wilaya of Tipaza despite the absence of activities such as composting and leachate treatment plants, the wilaya's landfill sites are spread over three LTCs (Gouraya, Meurad, Attatba and a management center in Sidi Rashed), each of these LTCs has an access passage, a weighbridge, sorting sheds, and surveillance posts compared to the wilaya of Algiers account for one LTC (Hamici) (**figures 18, 19**).

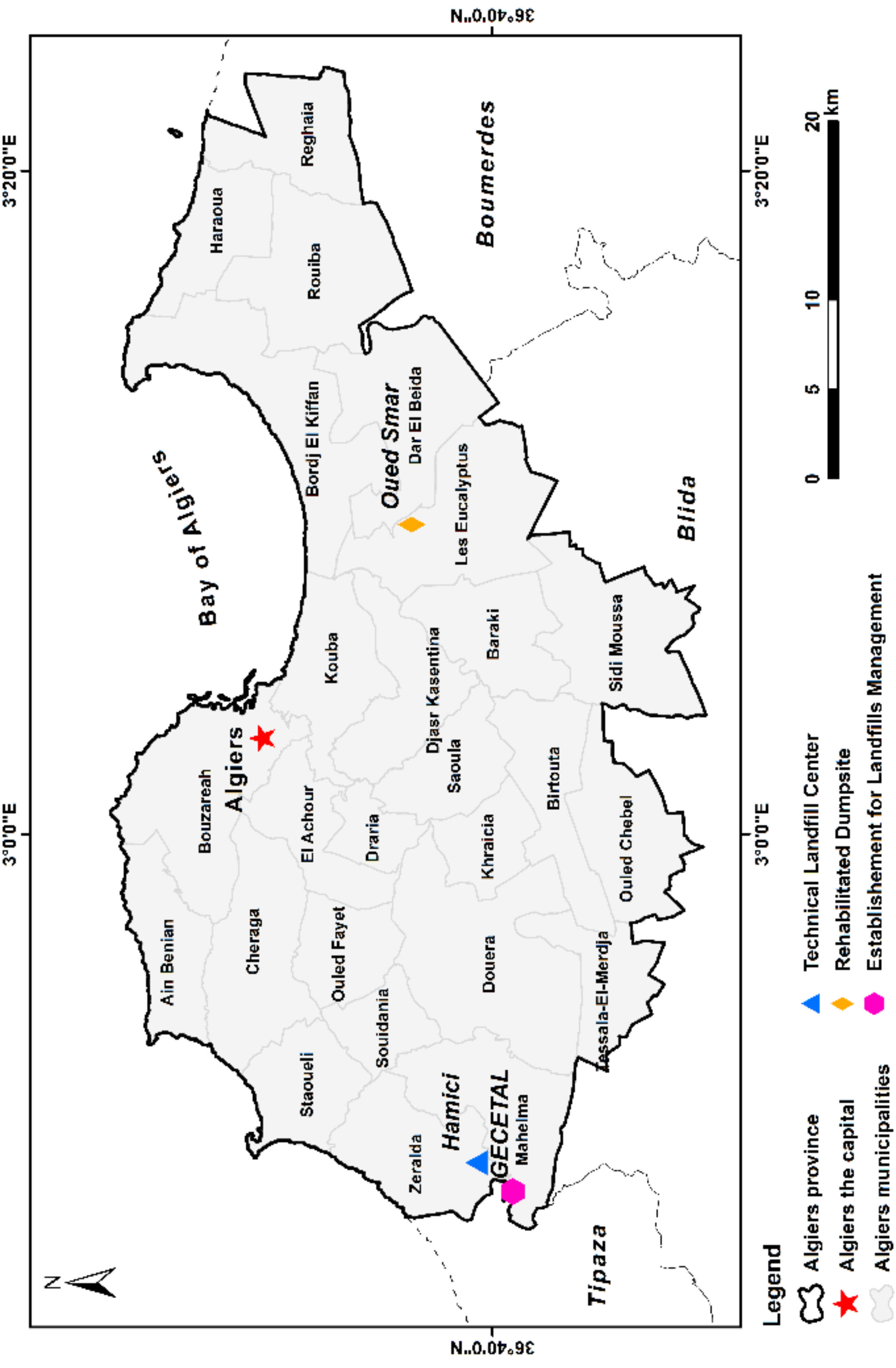

Figure 18. Technical landfill location in the wilaya of Algiers (google earth, 2021)

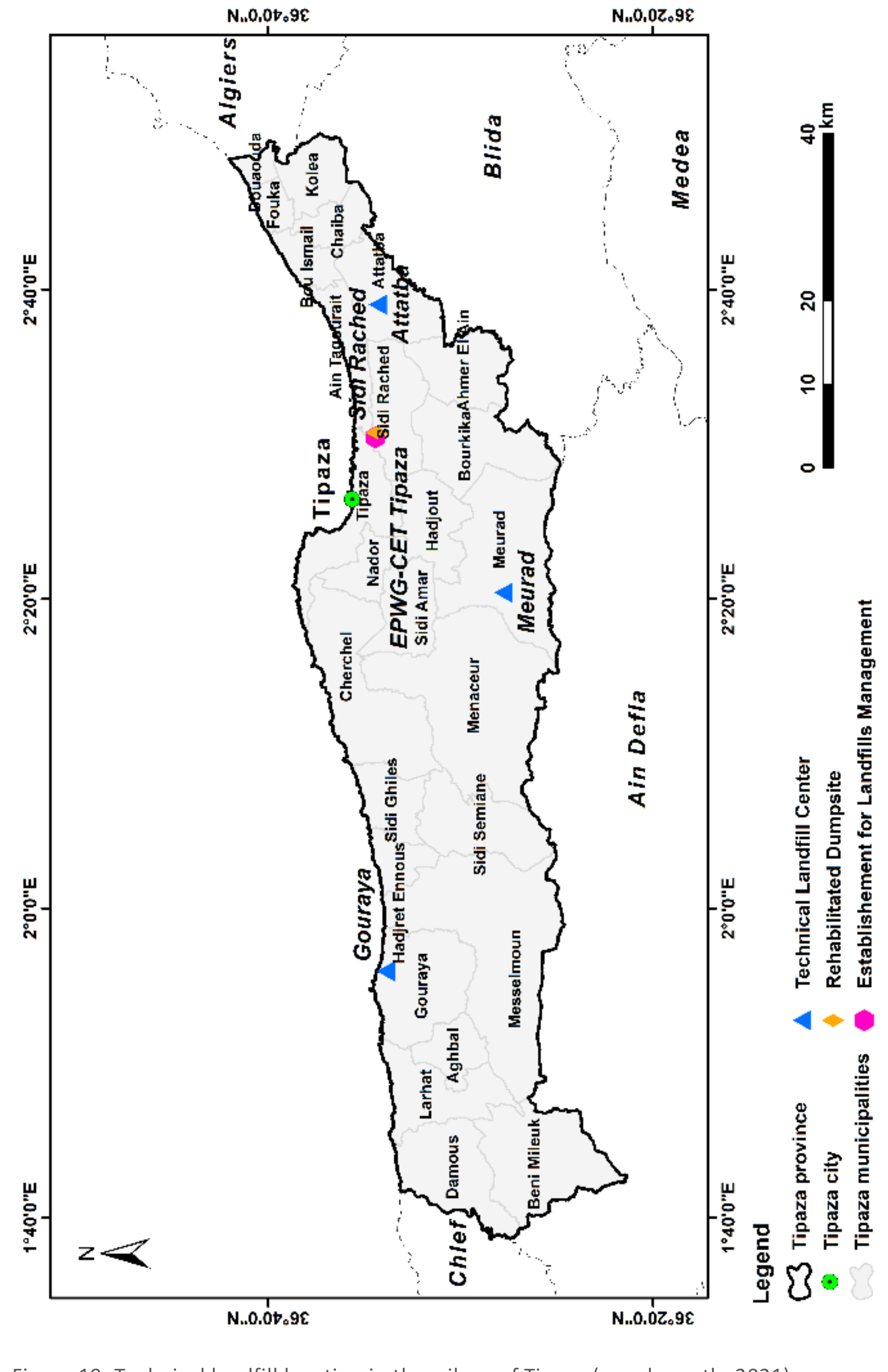

Figure 19. Technical landfill location in the wilaya of Tipaza (google earth, 2021)

4.3. Total ecological footprint of each wilaya

The computation of the EF by sector of activity provided a total EF of each wilaya, describing three components: material, energy, and built land. Tables **31** and **32** summarize the results and illustrate the difference in the EF between both wilayas, Algiers and Tipaza.

Table 31. The ecological footprint of activities in the wilaya of Algiers and Tipaza (2015)

Activity sector	Algiers			Tipaza		
	Material gha	Energy 10^3 gha	Built land gha	Material gha	Energy 10^3 gha	Built land gha
Fishing	15338.5	11. 95	176.78	275 030.4	1.49	15.29
Food	823 000	14.0	2.36	1 015 000	20.9	16.1
Forest	3 265.3	[-]	[-]	856.7	[-]	[-]
Water	[-]	2.22	[-]	[-]	6.36	[-]
Urbanization	[-]	20 227.1	1461.7	[-]	279.9	85.3
Urban waste	[-]	488.6	89.51	[-]	92921.2	39.16

Table 32. The total ecological footprint of the wilaya of Algiers and Tipaza (2015)

Total wilaya		EF (gha)	EF (gha/habitant)
Algiers	Material	840 402.6	0.3
	Energy	61 292 597.5	19.4
	Built land	1 730.35	$5.48*10^{-4}$
	Total EF	62 137 566.4	19.7
Population of Algiers	Inhabitant	3 154 792	[-]
Tipaza	Material	1 312 945.9	2.0
	Energy	1 358 633.3	2.1
	Built land	155.85	$2.35*10^{-4}$
	Total EF	2 671 814.2	4.0
Population of Tipaza	Inhabitant	661 247	[-]

The wilaya of Algiers has reached a total EF of 62 million hectares for a population of over three million inhabitants. Consequently, the latter's demand on hypothetical land required to sustain its resident's activity is 23 times that of the wilaya of Tipaza, whose population is almost five times smaller.

The EF of the wilaya of Algiers is represented at 99% by the energy component, demonstrating a more important economic activity. This is reflected in the urban planning and waste management sectors, where both sectors have high energy consumption associated with transportation operations. This energy is described as "operational" energy, thus visible in the energy balance of the urban waste management activity. Conversely, energy consumed during transportation in the urbanization sector is described as an "embodied" energy incorporated in the manufacturing life cycle of the building materials.

The energy EF (EF_c) of the wilaya of Tipaza exceeds that of Algiers in two sectors, namely the food sector, probably due to the important agricultural production in the wilaya of Tipaza, as well as the water production sector, which could be associated with either greater production or data availability.

The "Material" component, which ranks second in total EF contribution, is considerably more important in the wilaya of Tipaza (49%) due to the large fisheries, crop, and livestock production in the wilaya.

The last component, "EF_built," represents less than 1% of the total EF in both wilayas. This is mainly due to the EF study model that assigns a low yield factor to this unproductive land, although it is defined as a transformation of fertile surfaces. Second, due to a lack of data describing these infrastructures, not all infrastructures have been included (e.g., public facilities in the urbanization sector).

4.4. Demand for bioproductive areas

4.4.1. Estimation of biocapacity associated with the demand for surface

The assessment of the available bioproductive lands for the establishment and development of the different activities and the absorption of the CO_2 emissions that they generate in the study area was based on local data. Indeed, the collected statistics describe the physical extent of the lands used in each sector, namely cultivated surfaces (agricultural production), grasslands (livestock), fishing areas (marine fishing and aquaculture area), forest surfaces (wood production and CO_2 sequestration area), and infrastructure area (dwelling and individual houses projects) using the yield and equivalence factors of each type of land use (**Appendix 2**).

The cartography of the fishing surfaces and the extent of land occupied infrastructures provided input data to estimate the fishing, and the infrastructure BC, respectively. The figures and define the fishing surfaces of the wilaya of Algiers and Tipaza. Similar to the figures describing land use (**figures 14, 15**), th fishing grounds biocapacity has been estimated based, first on a delimitation of the fishing zones of both wilays (**figures 20, 21**).

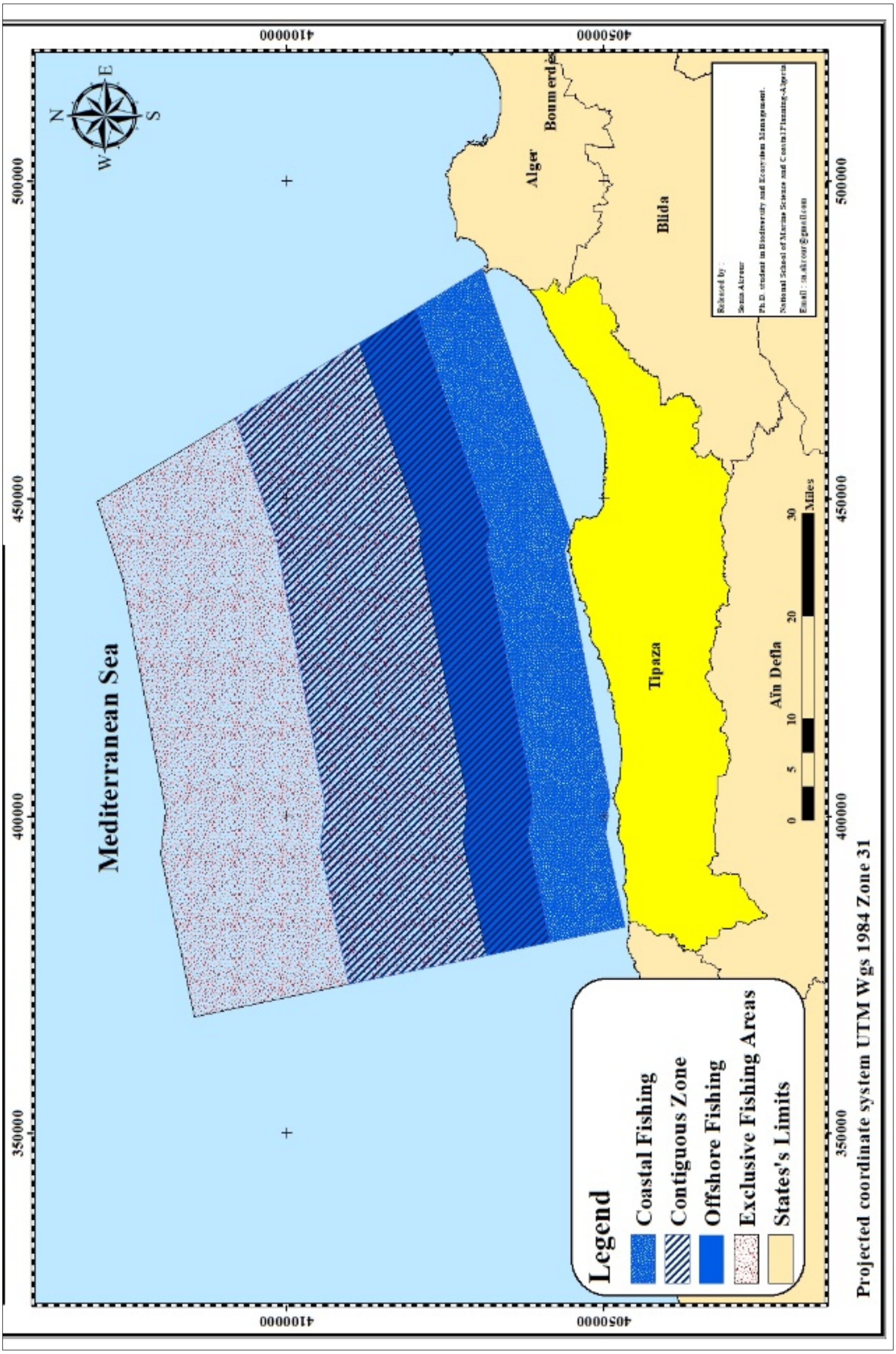

Figure 20. Delimitation map of Tipaza's wilaya fishing zones.

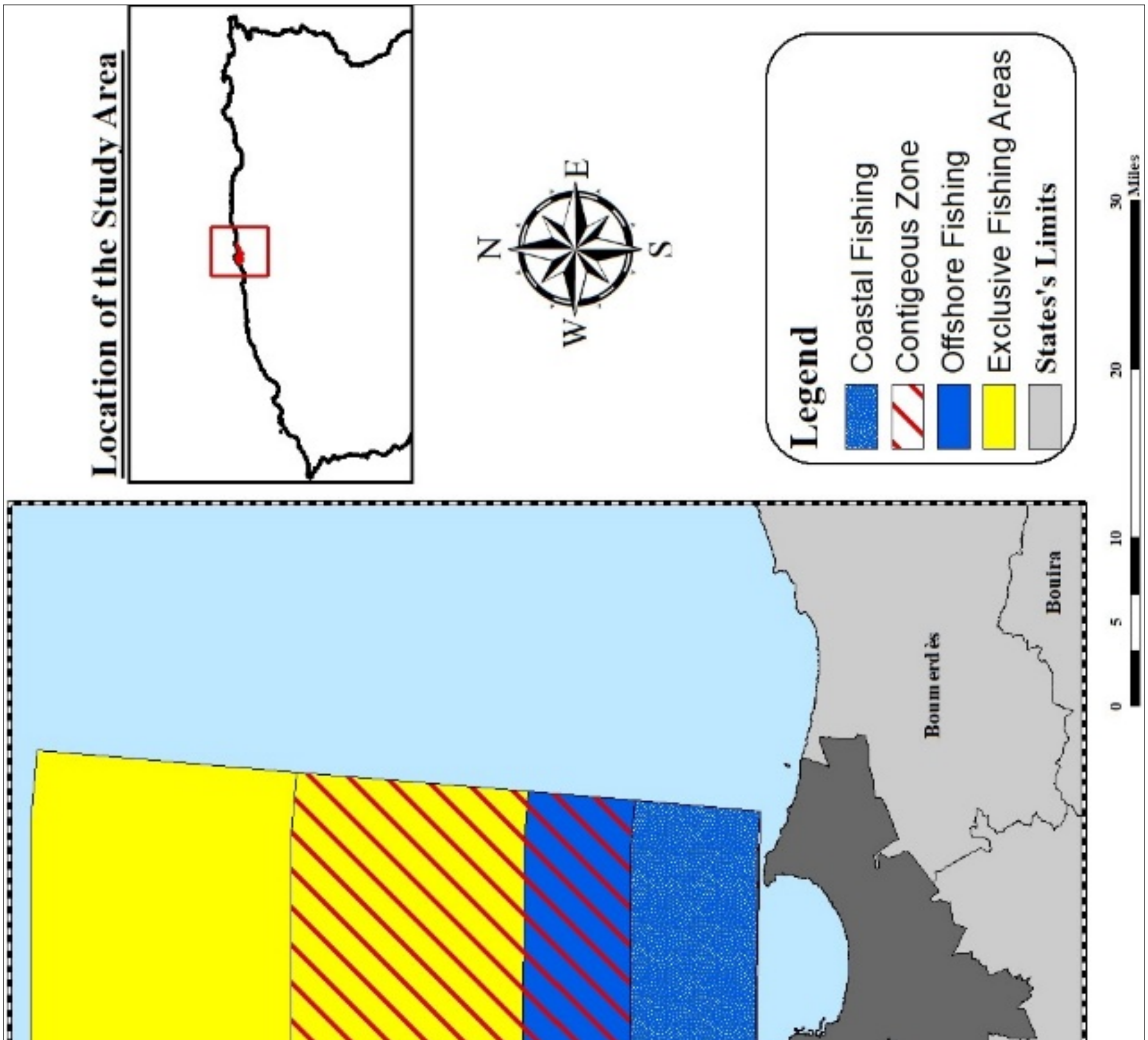

Figure 21. Delimitation map of Algiers' wilaya fishing zones.

It is noteworthy, that the shift from the bottom up model (component-based EF) to the top down model (end-use EF) requires defining for each sector of activity (this case study) the equivalent land use categories of the EF original model, i.e., the land types describes in the methodological approach. For instance, the "built land" component of all sectors is aggregated to obtain the "infrastructure" category of the original model. In contrast, the crop and grazing land areas are disaggregated from the "Material" component to obtain the two categories "cropland" and "grazing land" of the original model. Accordingly, the following tables (**tables 33, 34**) summarize the BC of each activity sector and land use for the both wilayas. The area dedicated to livestock grazing includes, along with the area of crops production (by-products used as livestock feed), the area of artificial fodder production and fallow land in described in the MADR inventory (2015 data).

Table 33. Estimated biocapacity by sector and land use category in the wilaya of Algiers

Activity sectors	Land types	Physical extent (ha)	Biocapacity (gha)
Fishing	Fishing grounds	309 495.3	108 787.7
Food	Cropland	14 160.5	13 203.2
	Grazzing land	28 278.7	8 907,8
Forests	Forests (sequestration area)	6 083	34 521.7
Fishing	Infrastructure	189.7	176.87
Food	Infrastructure	2.83	2.36
Water	Infrastructure	[-]	[-]
Urbanization	Infrastructure	1567.63	1461.7
Urban waste	Infrastructure	96	89.51

Table 34. Estimated biocapacity by sector and land use category in the wilaya of Tipaza

Activity sectors	Land types	Physical extent (ha)	Biocapacity (gha)
Fishing	Fishing grounds	335 602.1	124 994
Food	Cropland	47 476.6	44 267.2
	Grazing land	560 20.6	17 646,5
Forests	Forests (sequestration area)	76 126	43 209.1
Fishing	Infrastructure	16.4	15.29
Food	Infrastructure	17.27	16.1
Water	Infrastructure	[-]	[-]
Urbanization	Infrastructure	91.2	85.03
Urban waste	Infrastructure	42	39.16

4.4.2. Comparison between ecological footprint and biocapacity

The Global Footprint Network (GFN) produces annual maps describing the ecological status of countries (GFN, 2022). This cartography depicts the contrast between the country's demand for natural resources and the availability of bioproductive areas to produce and regenerate these resources. The NFA of the GFN describes the ecological status of Algeria as an ecological deficit, mostly due to the insufficient surfaces required to sequester CO_2 (forest surface). The ecological debt of Algeria is also reflected in other demand categories, i.e., cropland and fishing grounds (**figures 20, 21**), with overshoots of one to ten million hectares (GFN, 2022a). Accordingly, the wilaya of Algiers (the country's capital) was selected, assuming that the metropolises of the countries are indicative of the dynamics on a national scale. The GFN data (2022) and the study results made it possible to establish a comparison between the case of Algeria and its coastal wilayas (**figure 22**).

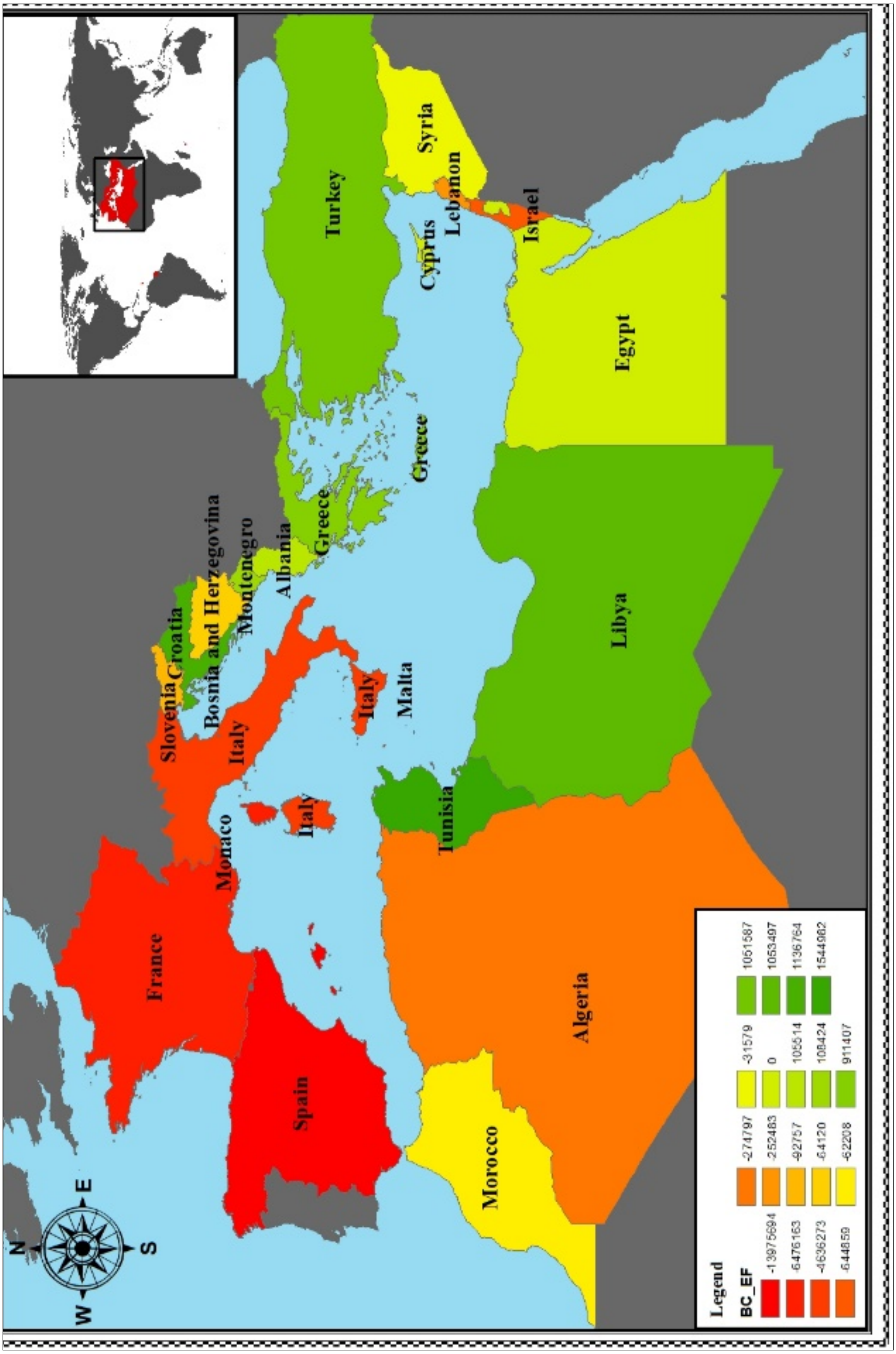

Figure 22. Mediterranean countries' fishing ecological footprint (GFN, 2016).

The three case scenarios display, with a few differences, the same trends in terms of demand on resources and their availability. Algeria and its two coastal wilayas requires a CO_2 sequestration land that exceeds 50% of all demand categories (**figure 23**). This demand is lower in Tipaza compared to Algiers where it is the majority. In the national case, this category of demand is followed by Cropland (25%), grazing land and forests (7%). In Tipaza the demand is slightly different marked by a significant demand for fishing grounds (10%).This is in line with the fishing sector's balance sheet (2015-2017) which shows that Tipaza held the first place in fisheries production during this period. Moreover, the demand for cropland in Tipaza is also above the national average (38%), reflecting the significant agricultural production of Tipaza.

The availability of bioproductive surfaces, the BC of both wilayas represent barely 0.01% of the total national BC (**figure 24**). In the national case, grazing areas represent half of the country's natural capital compared to the wilayas of Algiers and Tipaza, where fishing areas represent 65% and 53%, respectively. This can be explained by the nature of the data or by the difference between the two cases. Indeed, the national case comprise a larger extent of grazing areas, primarily because it includes other wilayas (the interior wilayas and the southern wilayas) of the country. In contrast, the dominance of the fishing grounds BC outlines the coastal character of the two wilayas. Furthermore, a study of the Mediterranean countries based on the fishing data of these countries labels Algeria among the countries in an ecological deficit (**figure 20**). However, this this study considers the local fisheries production of Mediterranean countries, and international trade. Accordingly, Algeria has negative balance due to the country's imports of fisheries products exceeding 30 thousand tonnes (ONS, 2019), represented at about 50% by frozen fish and fish fillets. Therefore, the EF of imports weighs on Algeria's total EF of fisheries.

To assess the relevance of the original model, the GFN's data (case of Algeria) were converted into the adapted component model (case of the two wilayas) by multiplying the data of the EF and the BC (per capita) by the population of the two wilayas (**Appendix 8**).

The results obtained through this method are largely different from the thesis findings. Indeed, biased overestimation results have been obtained in the case of the wilaya of Algiers, mostly due to the higher population numbers in Algiers. In the NFA rational, forest areas have the double function of producing forest products, such as wood and absorbing CO_2 emissions. The sum of these two claims (EF_forest and EF_c) compared to the forest BC, results in an ecological deficit associated with an exploitation that exceeds the capacity of forest ecosystems in the three cases. This deficit is more significant at the national level and at the level of the wilaya of Algiers, requiring more than 60 million gha, while the demand to Tipaza's wilaya's forest BC requires 1 million gha.

Algeria and the wilayas of Algiers and Tipaza also have some overshoot situations associated with other demand categories, namely: cropland for crops and fodder (three cases), grazing land (Algiers), Fishing grounds (Tipaza). Conversely, the three cases reveal an ecological reserve situation in other categories, such as grazing land (Algeria and Tipaza), fishing grounds and forests (Algiers), forest areas (Tipaza).

Overall, the three cases are in a situation of ecological deficit with a larger order of magnitude at the national level estimated at 79.03 million gha against 0.17 million gha and 0.22 million gha, for the wilaya of Algiers and the wilaya of Tipaza, respectively. Due to its population, the per capita ecological deficit recorded in the wilaya of Algiers is the highest estimated at -19.4 gha/inhabitant, which means that a citizen from Algiers' wilaya requires 19.4 hectares of average world production in addition to their annual budget of natural resources. The wilaya of Tipaza's citizens requires around 4 gha as a surplus. Surprisingly, the wilaya of Tipaza has the same EF profile as of the country. While Algiers represents an obvious case of ecological deficit, the wilaya of Tipaza, as well as Algeria present a part of the natural capital (forests and grazing areas) that can still meet the needs of the population and mitigate the impact of some activities (animal husbandry). The comparison between both wilayas and the national case provides guidance regarding the components and the activities or sectors associated with significant EF. Therefore, an indication regarding which activity should be of an urgent interest.

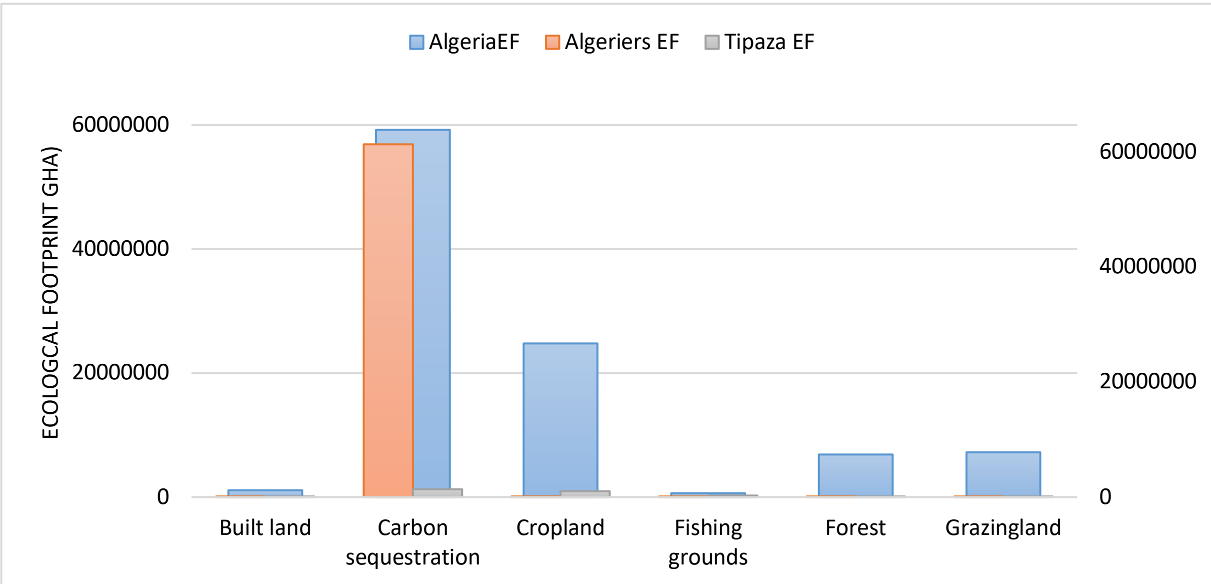

Figure 23. EF by demand category of Algeria, the wilaya of Algiers and the wilaya of Tipaza.

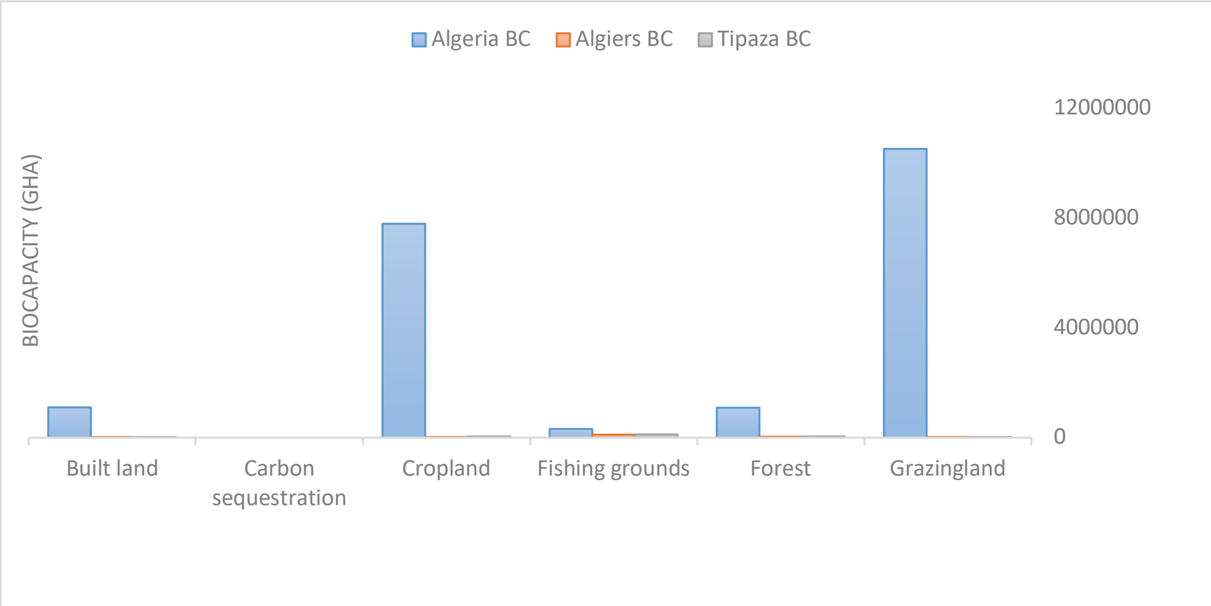

Figure 24. Biocapacity by land use categories for Algeria, Algiers and Tipaza.

CHAPTER 05. Constraints discussion

Algiers and Tipaza's wilaya ecological footprint assessments were performed in a complex context of data scarcity and model rescaling. Indeed, the primary ambitious objective of applying the original EF model to the entire coastal zone was redefined. The original model only applies to the national and international levels, as it considers global trade outputs. Moreover, some data is not produced at the local level, such as electricity production, which is generated for the national territory instead of one specific wilaya. Therefore, the study applied a component-based model using local data. However, data scarcity remained one of the main constraints of this study. This chapter describes the main contextual and conceptual constraints encountered during the EF assessment. This chapter describes the contextual (field-related) and conceptual (model-related) limitations.

5.1. Field-related constraints

This section lists the challenges associated with data collection, especially data availability and accuracy. The first difficulty is the structure and organization of statistics by the different management bodies of each activity. Consequently, data was selected based on its usefulness for calculating the EF. The following table (**table 35**) summarizes the criteria used to evaluate the statistic quality (High H, Low F, and Medium M).

Table 35. Data quality assessement

Sector	**Required data**	**Data Availability**	**Data Accessibility**	**Data Completeness**	**Spatial and temporal coverage**	**Relevance for EF assessment**	**Quality**
Fishing	Fleet's fuel consumption	Unavailable	[-]	[-]	[-]	Survey data	L
	Port energy (electricity) consumption	Available	Partially accessible	Incomplete	Data available at the level of SONELGAZ	Available Data for Algiers ports Only ECOREP data in Tipaza	M
	Infrastructures	Available	Accessible	Incomplete	Data describing Tipaza and Rais Hamidou fishing ports are not available	Useful data Could lead to an under-estimation of the built land's EF	M
Food	Energy consumption in agriculture	Unavailable	[-]	[-]	Desagre-gated data. Available by engine for each farmer	The calculation of energy EF was based on estimations	L
					Data available for both	Relevant for the estimate of	H

	Livestock and live-stock products	Available	Accessible	Incomplete	The quantity of animal feed is not available and was estimated	Relevant for the estimate of grazing land EF	M
Forest	Forest products (wood and timber)	Available	Accessible	Complete	DGF provides forest exploita-tion statistic for each wilaya per wood category	Relevant for the estimate of forest production's EF	H
	Forest operations	Unavailable	[-]	[-]	Data describing the engines used in silvi-culture are not available	No data to estimate the energy EF of forests	L
Water	Water production	Available	Easier access and communicati on in the wilaya of Tipaza	Complete	SEEAL provides data for the two wilayas by production source The water consumption data is only accessible at the wilaya of Tipaza	Relevant to estimate EF of water distribution	H
	Water distribution	Available		Incomplete	The description of the distribution network is more detailed in the wilaya of Tipaza	poorly repress-entative of the embodied energy in the manufacture of the water network's pipelines	L
	Water reservoirs	Available	Inaccessible	[-]	[-]	Hinders the estimate of the built land's EF	L
Building	Dwellings and houses	Available	Accessible	Complete	This data was used to estimate construction materials amount	Using dwellings inventory might have led to an overestimation of the energy EF	M
	Area of residential units	Available	Not readily accessible	[-]		These data are disaggregated. The area occupied by each housing entity is described in the documents which detail the housing project	L

Consumable waste	Waste material	Available	Accessible	[-]	Data is available and describes waste tonnage in both wilayas	Relevant and useful data for the estimate of the EF	H
	Waste collection and transportation	Partially available	Accessible	Incomplete	These data are more clearly structured in the wilaya of Algiers where waste management is managed by three entities. Desegregated in the case of Tipaza	Relevant for Algiers' energy EF estimate	M
	Management infrastructure	Available	Accessible	Complete	This data is clearly reported in both wilayas	Data is usable and relevant for the calculation of the built land EF	H

The above table summarizes the general cases of data availability. The data is often unavailable for describing a given activity's energy share, especially for transportation and engine use. This information is often not included by the operators of a specific activity, which typically focuses on the output of their activity (e.g., fishing, livestock, and silviculture). In addition, energy data is often the user's concern (fisherman, equipment operator). The latter is not efficient in the evaluation of their expenditure. For example, fishermen often estimate their energy expenditure in terms of daily monetary values. Moreover, they do not keep track of the actual amount of fuel used or other oil forms.

Data may also be collected by other entities related to an activity sector. For instance, in the case of fishing ;

- The fleet displacement and physical properties have been collected at the level of the SGPP,
- The landings have been collected at the level of the DPRH and the fisheries offices,
- The fishing trips, which the coast guards report, have been collected through a survey,
- The infrastructure is described by port works direction (DTP),
- The ports' energy expenditure (electricity) is provided by the SONELGAZ. The latter is inaccessible
- This is the case for many sectors and sometimes makes it difficult to obtain data.

Furthermore, one of the most frequent limitations is the data structure and organization, which is not standardized within the collection institutions of each sector. Indeed, the data can be differently arranged among the management entities (EPIC NRTCOM, EPIC EXTRANET), from one wilaya to another (DPSB Tipaza, DPSB Algiers), and for the same sector and for the same year from one management office to another, which is the case at the level of the DPRH of each wilaya. This case has been particularly challenging during the assessment of the fishing EF. Considering that the PPR calculation depends on the trophic level (TL) of the harvested species. Thus, each species has a well-defined trophic level, inventoried on Fishbase.

The description of the landings in the Algerian ports provides the common name of the species without the corresponding scientific name or FAO code, which led to the following cases (**table 36**).

Table 36. Encoutred cases associated with the description of the fisheries landings

Case	Examples	Impact on the EF calculation
Untraceable	Chpernouk, Tchoucla	Underestimation due to missing data
Imprecise	Mullet. Is it *Mullus barbatus* or *Mullus surmuletus*?	TL =3.15 TL=3.42
Multiple names for the same species	Chelba, Salpa, Saupe, Tchelba	Double counting
Acronym	"CR" which can correspond to (crevette royale) the royal shrimp (*Penaeus kerathurus*) (crevette rouge) caramote prawn (*Aristeus antennatus*)	TL= 2.7 TL= 2.3 The difference is insignificant. However, it could be misleading.
General designation	Divers mollusks, Divers crustaceans	It is complex to define the TL for these categories. Selecting an average TL value could lead to under or over estimation of the PPR

5.2. Model-related limitations

The EF assessment model is a computational tool for analyzing a single dimension of sustainable development: the annual resource budget available to a population and the appropriation of that yearly budget by the population. The calculation of the EF is performed using two different methods, namely the basic model (top-down approach) or the downscaled model (bottom-up approach). Both models provide valuable outcomes. However, they present some limitations related to the EF concept, mainly:

5.2.1. Bioproductive areas

All "unproductive" land for human use is not taken into account by the EF model (Lenzen & Murray, 2001), despite the usefulness of these ecosystems for biodiversity, which in turn can benefit humans. Therefore, large areas such as the desert or boreal grassland are excluded from biocapacity calculations in the standard EF methodology (Venetouli et al., 2008).

5.2.2. Infrastructure

The infrastructure EF and BC estimates use the same YF equivalence factors. The comparison between the demand and the supply does not indicate an overshoot, particularly in the original model. Therefore, it would be appropriate to compare the infrastructure's EF with cropland's BC, considering that both categories are associated with the same EQF (2.52gha/ha), as the rationale of the EF stipulates that humans ideally settle on fertile land. Comparing infrastructure with agricultural or forest land (vegetation cover) would be more appropriate for defining the pressure this activity exerts on natural ecosystems.

5.2.3. One type of waste

The EF accounting considers only carbon dioxide a waste product of human activity. The selection of this gas is based on the assumption that CO_2 is the most GHG generated. Nevertheless, considering their global warming potential, other GHG emissions, such as landfill gases, could be more dangerous.

5.2.4. Forest, the only sequestering ecosystem

In the same demand category (point 3), the NFA considers forests the only ecosystem for CO_2 sequestration, although other terrestrial and aquatic ecosystems sequester this gas. Removing the fraction sequestered by ocean ecosystems (1-Socean) hinders the evaluation of marine and coastal plant areas, such as seagrass meadows, required for sequestration, and thus pressures these ecosystems. Therefore, including marine and coastal ecosystems in calculating carbon dioxide sequestration capacity in EF calculations is expected to reduce the gap between EF (Carbon category) and BC (all vegetation cover).

5.2.5. The life cycle analysis

The component-based approach is data intensive. In the context of scarcity or non-existence of data, these statistics are produced by life cycle analyses (LCA), especially when evaluating energy use and associated emissions through the products supply chain. However, it is essential to reiterate the complexity of this type of analysis, especially the initial definition of the study boundaries. Indeed, LCA account for all the processes from the extraction of the fossil resource to generate energy and raw materials that are comprised in the manufacture a product to the deposit of this product (Inaba, 2004). Therefore, the origin of energy, the type and origin of raw materials, and the industrial manufacturing processes can change from one region to another and year to another.

Moreover, LCA are poorly documented in Algeria, and the available studies was not relevant for this study, except for Makhlouf et al. (2015) and Makhlouf et al. (2019). Most LCA emission factors were obtained from the literature (Moore et al., 2013; Scalet et al., 2013).

CONCLUSION

To understand the magnitude of human impacts on Algeria's coastal ecosystems, this work analyzes for the first time the ecological footprint (EF) of two coastal wilayas, Algiers and Tipaza. The selection of both wilayas was motivated a contrast between the wilaya of Algiers and that of Tipaza. Indeed, the wilaya features intense human activity compared to the wilaya of Tipaza, in which "naturality" reflects a reduced human pressure on its ecosystems and their functions. Considered as an environmental and natural resource indicator, the EF measures the hypothetical extent of natural ecosystems required to provide goods and services expressed in global hectares (gha), compared to the natural capital (biocapacity) available to the settlement and the development of a given population's socio-economic activities.

The EF is reported worldwide by the global footprint network (GFN), which compiles annual national accounts of EF and BC based on international data. For instance, the GFN classifies Algeria as ecologically deficient with a total EF of 1.9 gha/capita (GFN, 2014), which implies that an Algerian citizen appropriates 2 ha of average world production for his development. This description, based on estimates, proxies, and which provides a distorted image, was one of the primary motives for investigating Algerian wilayas' EF. With 100 million gha, Algeria is ranked 21st in the Mediterranean with a Biological capacity (BC) and a per capita EF below the world average compared to the North Western Mediterranean countries such as France, Italy, or Turkey, whose BC and EF exceed the world average. Algeria's excess between the BC and the EF is mostly associated with its high imports.

This import's EF is one of the first concerns raised about the standard EF model, since the EF of imported products is added to the EF of local production, from which exports' EF is subtracted (thus a negative balance in international trade). The resulting consumption EF (EFc) is then compared to the local BC (the only areas considered by the EF concept). The interpretation of the outcome is complex, especially since imported products require productive surfaces beyond the country's geographical limits. Accordingly, a country with a negative trade balance is dependent on the provider county's BC and a high EF value compared to its local available natural capital. As a matter of fact, if Algeria's local production EF was compared to its local BC, Algeria would be in a state of an ecological reserve. Which is not the case, because the EF is funded on and considers the needs of a population (locally produced and imported goods). However, imported products are associated with energy, thus CO_2 emissions, during their production in the countries of origin (91% carbon EF) and international transport (9% carbon EF). Therefore, it appears that the country's natural capital will constantly be deemed insufficient to carry the population's activity, especially for carbon sequestration ecosystems (in this case, forests).

The original model takes accounts for the international trade. However, in this thesis work, we have considered only the local production of the two wilayas analyzed. Based on a bottom-up approach, the model uses locally collected data and displays overshoot points for three components: material, energy, and built area. The main findings reveal that Algiers and Tipaza wilayas are facing an ecological deficit, which is greater in the wilaya of Algiers (62 million gha). This result was anticipated for the wilaya of Algiers, selected precisely to demonstrate the effects of socio-economic activity intensity. Moreover, considering that it is the country's capital and one of its metropoles, it is assumed to reflect the ecological state of the country. Nevertheless, the wilaya of Tipaza is a striking case, since it was selected mainly for its less intense activity and significant natural assets (wider marine area and forests).

The ratio between the EF of Algiers (calculated) and the EF of Algeria (GFN, 2014) indicates that the EF of an Algeriers' citizen is eight times that of an average Algerian. While its surface area equals 0.03% of the national territory, and its biocapacity hardly exceeds 0.8%. Based on the rationale of a GFN study (GFN/Mava, 2015), the theoretical area that Algiers requires for its development exceeds the national capacity by more than 200%, meaning that Algiers consumes beyond its administrative boundaries. Thus, Algiers follows the same trend as some Mediterranean cities (Cairo, Athens, and Tunis). It is worth noting that besides its local residents, the wilaya of Algiers is a host to an important flux of "temporary population" which enters the city on a daily basis. Indeed, aside from its permanent population, residents of nearby wilayas such as Blida, Boumerdes and Tipaza join the city every day for multiple purposes, including work with about 130,000 trips made daily, according to the SDAAM[35] (Safar-Zitoun & Tabti-Talamai, 2009). Additionally, the consumption discrepancy between Algiers and the other wilayas of the country is substantial in several domains. For instance, the wilaya of Algiers boasts public lighting four times more important than that of the wilayas of Sidi Bel Abes and El Taref and five times more than that of the wilaya of Bechar (SONELGAZ, 2018). Another example is household and similar waste production, in which Algiers produces 1.26 times more waste than the wilayas of Jijel, Constantine, M'Sila, and Ouergla combined (AND, 2018; 2020). By comparison, the demand for bioproductive areas in Tipaza does not exceed 13% for 2% of the population, living in 0.09% of Algeria. It is in the same range as cities like Valencia (Spain) and Genoa (Italy), although the area ratio between these cities and their country is significantly lower.

In addition to a final diagnosis of the ecological status of each wilaya, the bottom-up model provides further description. The latter helps to understand the overshoot occurrence. In both wilaya, the footprint associated with energy use, thus the carbon EF is the highest component. This carbon EF is associated with every considered activity in both wilayas. We suppose that the overshoot in CO_2 emissions and uptake zones could be related to an overestimation, primarily due to data scarcity regarding energy use, which had to be generated by other integrated analysis, such as the urban metabolism analysis and life cycle assessment (LCA). Regarding the energy land footprint or the EF of sequestration areas, the footprint considerers "forests" areas (Ewing et al., 2010). However, it is not the only carbon offset mechanism (Blomqvisk et al., 2013; UNFCCC, 2018), as more than 80% of the carbon cycles through the oceans (IUCN, 2017). Indeed, marine and coastal ecosystems represent one of the major carbon pools (blue carbon). For instance, the total carbon content in seagrass and salt marshes

[35] SDAAM Schéma Directeur l'aménagement de l'Aire Métropolitaine D'Alger (Master plan of the Algiers metropolitain area).

is estimated at 236.76 and 197.16 Mg C/ha, respectively (99% is soil organic carbon) (Sathiyamohan, 2021).

Moreover, it could be complex to model the carbon sequestration process in a limited region (administrative boundaries), leading to the question: where should this sequestration land be located? Especially for carbon emissions generated by transportation, as transportation activity remains the major source of GHG emissions in developing countries (Nabavi-Pelesaraei et al., 2017). Another comment could be attributed to the interpretation of this EF component, as the equivalent required land to sequester carbon estimate is based on the sequestration capacity of forests, which differs as a function of climate (e.g., temperate, boreal). It is also worth noting that these ecosystems are also associated with other services, such as providing wood for heat and construction. In this case, we would precisely argue the EF's effectiveness in depicting several demands on one productive area. It is also the case for cropland, which serves as the provider of a resource (crops, animal feed), habitats (soil biodiversity), and human settlement lands (infrastructures). However, the pressure exerted on these bioproductive areas is poorly illustrated by the EF. Indeed, other than changes due to reducing physical hectares (e.g., bushfires), their regenerative capacity seems "unalterable" over the years, neglecting the state of these lands (Van den Berg et al., 2013) and the used technologies (Lenzen & Murray, 2001). This oversimplification in the productive lands' biological capacity assessment is primarily due to the use of the FAO's Global Agro-Ecological Zoning model, which considers five land categories index based on potential crop productivity (Borucke et al., 2013; Wackernagel et al., 2020). Some authors introduced the net primary production appropriation to improve this accounting issue, particularly the demand for fishery products (Talbert et al., 2006) and grazing land (refined NFA, since 2008). Consequently, accounting for the amount of available biomass required to feed the "consumable" biodiversity or to produce animal meat and related products (e.g., milk) provides the EF the ability to measure humans' share of resources and, indirectly, its reliance on this biodiversity. Furthermore, this estimate is relevant as it sets thresholds (similar to the maximum sustainable yield) expressed in primary production (De Leo, 2013; Akrour & Grimes, 2022). The latter is better illustrated at the local level, avoiding aggregated data related to trade.

Whether the wilaya or the national case, both models are data-intensive and have advantages and shortcomings (Simmons & Wackernagel, 2000; Wiebe et al., 2016). The bottom-up model, or the component footprint, requires LCA output data, especially for the embodied energy in production processes (fertilizers, consumables) and operational energy. Indeed, LCA approaches are advantageous, as they provide an accurate description of the upstream supply chain emission to build a carbon inventory (carbon footprint) (Swiader et al., 2018), which could then be converted into the equivalent offset area (ecological footprint of carbon). Therefore, the model's limitations are those of the LCA: the definition of the study boundaries (cradle to the gate or cradle to grave), the LCA databases used, and the proxy in case of data deficiency. Indeed, the component approach requires adjustment to the study area, data availability, and the use of proxies (El Bouazzaoui et al., 2007). Nevertheless, even the LCA studies are poorly documented in Algeria or recent and cover a specific activity. Therefore, LCA should be refined to avoid over or under-estimating CO_2 emissions, thus, a greater or smaller EF. This focus should be allocated to energy use, especially in the sectors using fossil fuel equipment.

It is also important to emphasize that data challenges were not limited to availability. The latter was also associated with the form and structure of the data, as described in the chapter (constraints). For instances, for the same information, the data is structured and described differently: from the international to the national level (FAO code for agricultural and forest products), from one wilaya to another (wilaya's profile, more detailed in the case of Tipaza), and from one administrative body to another within the same wilaya (fisheries division). Furthermore, a lack of complementarity between socio-economic activities was observed, as the information inventories neglected specific data (fuel consumption during fishing trips and the surface area occupied by public equipment). It was noticed during the exchange with the management entities that for each sector of activity, the managers analyze and develop management plans limited to this activity without considering the usefulness of information for the connected or dependent sectors. The state of data in Algeria is evidence of the emerging utility and robustness of the bottom-up method. Indeed, as structured in this study, the EF accounting provides a standardized framework for data collection and processing across all sectors of activity based on data that they collect and can reflect on.

The present work demonstrates the applicability of downscaled EF to the cases of the wilayas of Algiers and Tipaza. In addition, the information describing the ecological status of these wilayas confirms the relevance of this indicator to support resource consumption management and human activities monitoring policies.

However, decision-making should be aware that this tool is informative enough to investigate sustainable consumption instead of sustainable development (SD). The EF examines one aspect of SD, while SD comprises several dimensions that could be tackled from various angles. Indeed, a country with particular natural assets, such as "fisheries production" or "minerals," could be struggling with economic progress if it does not possess the technologies to extract and exploit these resources. By providing a detailed EF per component, the component-based EF provides insights into which component to target and the impact occurrence. However, the EF outcomes should be considered cautiously. For instance, Tipaza's fishing grounds' ecological deficit should be reviewed. Indeed, in this study, Tipaza fishing grounds seem smaller and insufficient to sustain the Tipaza fishing fleet's landings. A further investigation comparing the required primary production (instead of physical areas) to sustain the fishing activity revealed that Tipaza's coastal waters' available biomass is higher than the exploited biomass.

The contribution of this study lies in the information and diagnosis that the multilevel model provides to decision-makers to understand the challenges of achieving sustainability of a given sector. We suggest applying this approach to a broader region for greater representativeness and broader coverage of material and energy flows across sectors of activity. For example, along the Algerian coast should be considered as a single study area to investigate the EF of fishing. Furthermore, the following aspects should be considered for future studies:

- Material lifespan (concrete, steel pipes) to amortize the resulting CO_2 emissions from the manufacturing processes.
- Use of updated, ideally local, LCA database.
- Investigate transport's share in energy use for each activity, such as dwelling construction.
- Considering the total urban fabric (e.g., industrial zones) instead of residential infrastructures.
- Integrating other production surfaces, such as desert forests (Southern wilayas).
- Refining the estimation of bioproductive surfaces. As a matter of fact, Venetoulli et al. (2008) consider that about 36 billion hectares of land considered unproductive are excluded from the NFA.
- This leads us to our main suggestion of including coastal and marine ecosystems in the estimate of carbon sequestration areas.

Prior to assessing the sustainability of an activity, a city or a region, this study provides a standardized framework for data collection among the several socio-economic sectors, which covers all related component of an activity. Indeed, such a device would be helpful for data collection and a cross-sectors synchronization. Considering these aspects will surely reinforce the effectiveness of the model used in this study. Most importantly this study could also serve as the first document for the popularization of the ecological footprint concept and calculation in Algeria, as well as a baseline for public outreach programs on resource use and eco-responsibility.

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Appendix 1. The Ecological Footprint EF and Biocapacity BC calculation scheme

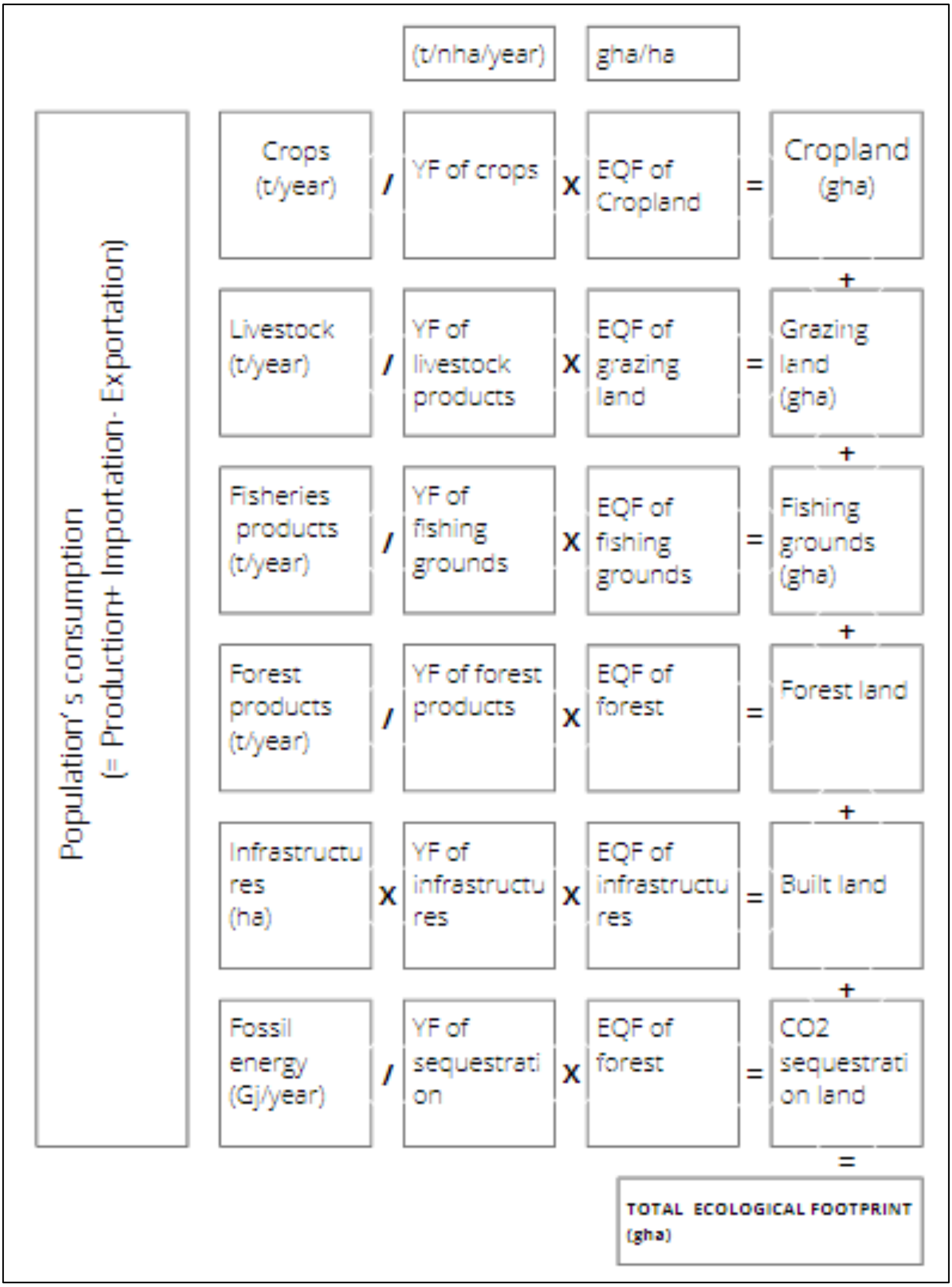

Figure 25. Basic structure of Ecological Footprint calculations

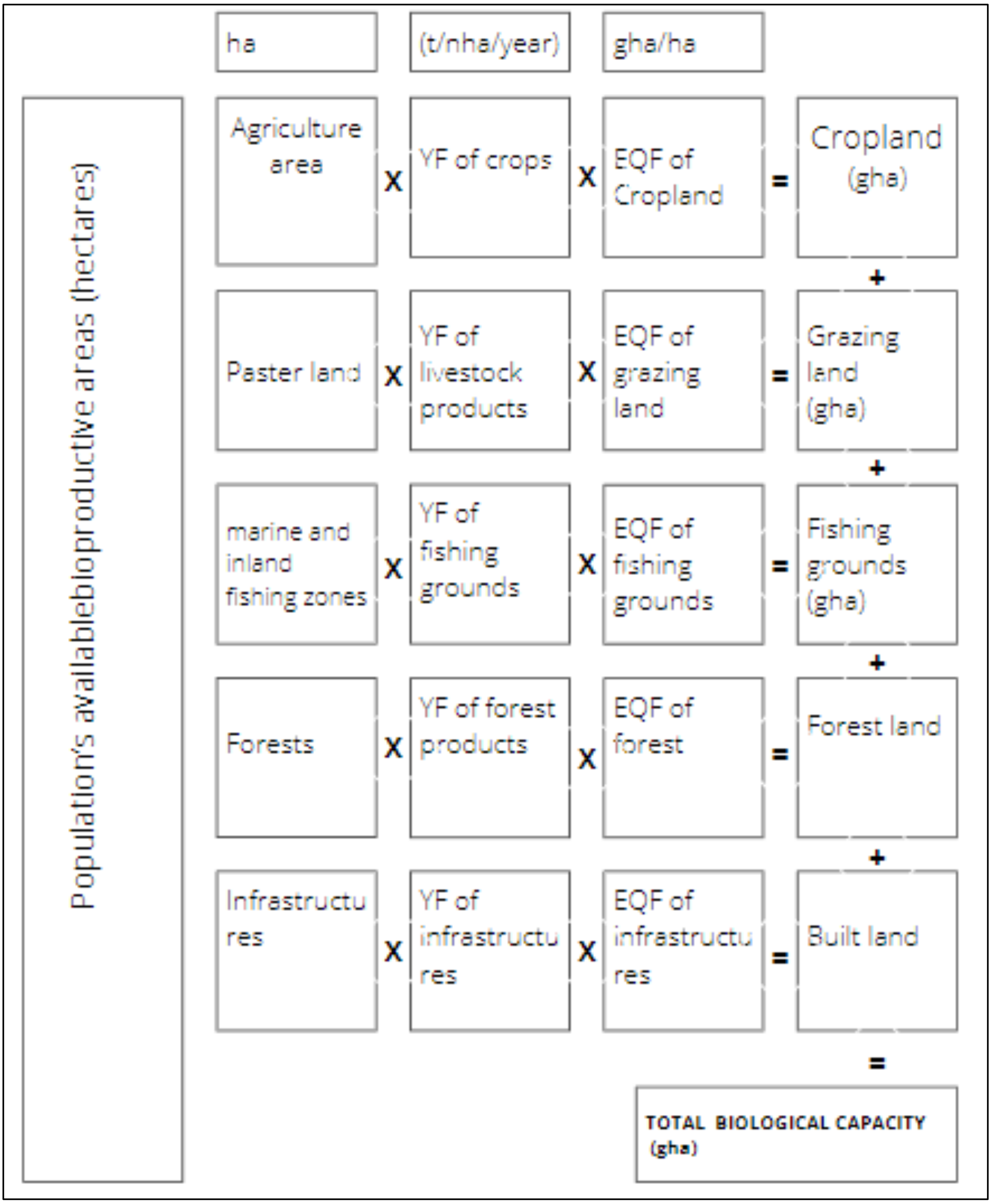

Figure 26. Basic structure of Biocapacity calculations

Appendix 2. National Ecological Footprint EF Accounts.

The following tables describe Algeria's National Ecological Footprint NFA and Biocapacity Account of 2014 (**table 37**), the final grazing area estimation matrix based on livestock statistics per capita (**table 38**) and the conversion factors (Yield and Equivalence Factors) from the GFN latest edition (GFN, 2019).

2.1. National Ecological Footprint and Biocapacity Accounts of Algeria for 2014

Table 37. Algeria's National Footprint Accounts for 2014

National Footprint Account 2018 edition - Year 2014					
Algeria					
Total Ecological Footprint and Biocapacity					
Type of demand	**$EF_{Production}$**	**$EF_{Imports}$**	**$EF_{Exports}$**	**$EF_{Consumption}$**	**Biocapacity**
[-]	[gha]	[gha]	[gha]	[gha]	[gha]
Cropland	7 898 586	15 054 687	266 839	22 686 434	7 898 586
Grazing land	4 894 426	2 241 842	1 712	7 134 556	10 670 903
Forests	3 350 301	3 409 309	19 717	6 739 892	1 100 761
Fishing ground	295 055	313 499	7 394	601 161	321 257
Built land	1 092 607	[-]	[-]	1 092 607	1 092 607
Carbon	45 706 752	17 496 402	6 117 231	57 085 923	[-]
TOTAL	**63 237 726**	**38 515 739**	**6 412 893**	**95 340 573**	**21 084 114**
Ecological Footprint and Biocapacity per person					
Type of demand	**$EF_{Production}$**	**$EF_{Imports}$**	**$EF_{Exports}$**	**$EF_{Consumption}$**	**Biocapacity**
[-]	[gha person^{-1}]	[gha person^{-1}]	[gha person^{-1}]	[gha person^{-1}]	[gha person^{-1}]
Cropland	0.20	0.39	0.01	0.58	0.20
Grazing land	0.13	0.06	0.00	0.18	0.27
Forests	0.09	0.09	0.00	0.17	0.03

2.1. Calculation principle of the ecological footprint (EF) of grazing land:

The EF of grazing land is the surface demand for livestock feed's production (grass, crops, fisheries products such as fishmeal) required to support the production of livestock products such as meat (red and white), dairy and other products (honey, eggs, wool).

Thus, EF is based first on the need for livestock while considering their equivalent daily consumption and their average demand for food. Accordingly, the EF is calculated for the different categories of area food production (e.g., area required to produce crops, fodder, or crop residues). Ultimately, the EF of the grazing lands is the sum of these demands. The following table details the EF of the grazing land of the wilaya of Algiers and Tipaza.

Table 38. Estimation of the EF of grazing land of Algiers' wilaya based on the NFA matrix

Name	Units	Buffaloes	Cattle	Goats	Horses	Sheep	*Total*
FAO Code	[-]	946	866	1016	1096	976	
HS+ Code	[-]	0102_b	0102_a	0104.20	0101_a	0104.10	
Feed Name	[-]	Cattle and buffaloes	Cattle and buffaloes	Sheep and goats	Horses	Sheep and goats	
Feed Code	[-]	866	866	976	1096	976	
Heads	[head]	**525**	**35 813**	**3 614**	**879**	**7 077**	**47 908**
Feed Intake	[kg dm head^{-1} day^{-1}]	6,8	6,8	1,0	10,0	1,0	
Feed Demand	[t dm yr^{-1}]	1 303	88 887	1 319	3 208	2 583	*97 301*
% Grass Feed	[t dm yr^{-1}]	69,0%	69,0%	100,0%	69,0%	100,0%	
Crop and Fish Feed Demand	[t dm yr^{-1}]	-	-	-	-	-	-
Grass Feed Demand	[t dm yr^{-1}]	-	-	1 319	-	2 583	*3 902*
Expected Crop	[t dm yr^{-1}]	404	27 555	-	995	-	*28 954*
Expected Grass	[t dm yr^{-1}]	899	61 332	1 319	2 214	2 583	*68 347*
Expected Fish	[t dm yr^{-1}]	-	-	-	-	-	-
Expected Crop EF	[gha]	-	-	-	-	-	-
Expected Grazing EF	[gha]	316	21 567	464	778	908	*24 034*
Expected Fish EF	[gha]	-	-	-	-	-	-
Total EF	[gha]	**316**	**21 567**	**464**	**778**	**908**	**24 034**

2.1. Conversion Figures for Ecological Footprint and Biocapacity Calculation

The following tables resume the 2019 yield factors YF and equivalence factors EQF associated with Algeria (GFN, 2019).

Table 39. Algeria's YF according to the latest NFA (GFN, 2019)

Type de terre	**Rendement moyen**		**Facteur de rendement**
	National	**Mondial**	
Cropland	5.07	13.66	0.37
Grazing Land	4.38	6.19	0.70
Marine fishing grounds	480	503.84	0.95
Inland fishing grounds	0	0	1
Forest area	0.79	1.82	0.44
Infrastructure	0	0	0.37

Table 40. Algeria's EQF according to latest NFA (GFN, 2019)

Land category	**Equivalence factor**
Cropland	2.52
Grazing Land	0.45
Marine fishing grounds	0.36
Inland fishing grounds	0.36
Forest area	1.28
Infrastructure	2.52
CO_2 Sequestration land	1.28

Appendix 3. Life cycle assessment through GEMIS software

3.1. Global presentation

GEMIS or Global Emission Model for Integrated Systems is an open source tool for assessing the environmental impacts and costs of energy, materials and transportation systems.

- Air Emissions (SO_2, NOx, particles,).
- Greenhouse Gases (CO_2, CH_4, N_2O ...).
- Waste Water (AOX, DBO, DCO, N et P).
- Solid waste (Ash, residues from combustion gas treatment, production waste).
- Resource use (primary energy, raw materials and land).

In addition, GEMIS evaluates economic costs and employment records.

3.2. Software Structure

The software platform has three main windows: product, process and scenario.

3.2.1. The Product

The GEMIS defines products as the inputs and outputs of processes. The products contain the information needed to calculate the energy and environmental characteristics of the processes. The GEMIS standard database includes more than 750 basic product types.

Product types are defined as follows:

Energy transporters, products entering or leaving a process, other than fuel, it may be electricity from steam or hot water.

Materials, products entering or leaving a process as energy carriers (chemical compounds, building materials, industrial products and agricultural products...).

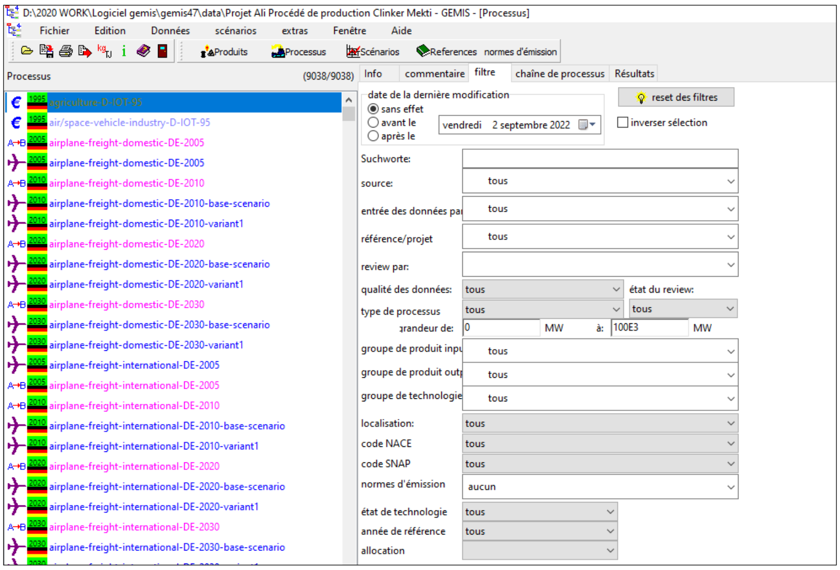

Figure 27. GEMIS 4.7 Software Product Window

3.2.2. The Process

GEMIS defines a series of processes comprising a set of operations to transform the input product into an output product. A process includes as well other auxiliary inputs (such as auxiliary energy, water), and may result in secondary outputs (e.g. emissions of harmful substances).

The selection of processes can be selected using filters (**figure 28**) discernible by various symbols. These filters define the category, year, country and the database used, and the user. GEMIS includes the following types of processes :

- Energy transformation (Energy conversion), combustion, heat exchangers, turbines.
- Material processing (Conversion), production of steel, chemicals and more.
- Incineration (Combustion).
- Materials extraction and acquisition, such as oil, minerals and fuels.
- Transportation of goods and persons by various means of transport
- Waste treatment (Waste treatment facility).

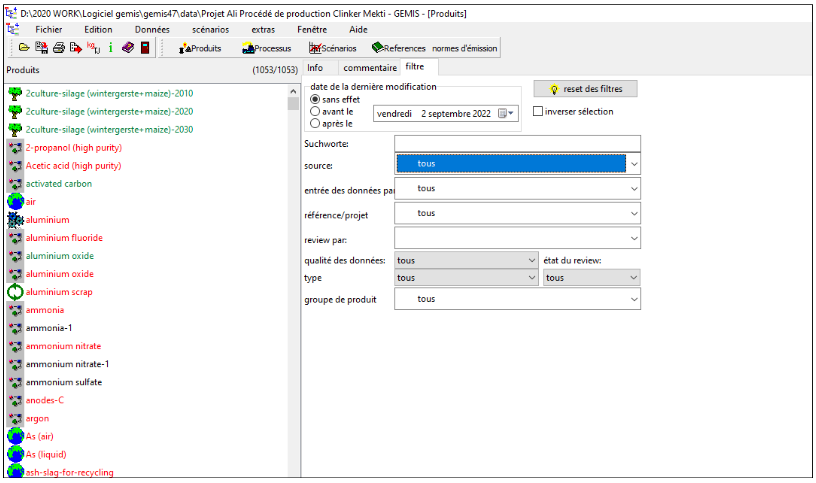

Figure 28. GEMIS 4.7 softaware processes window

The process can be visualized as a chain or process tree (**figure 29**)

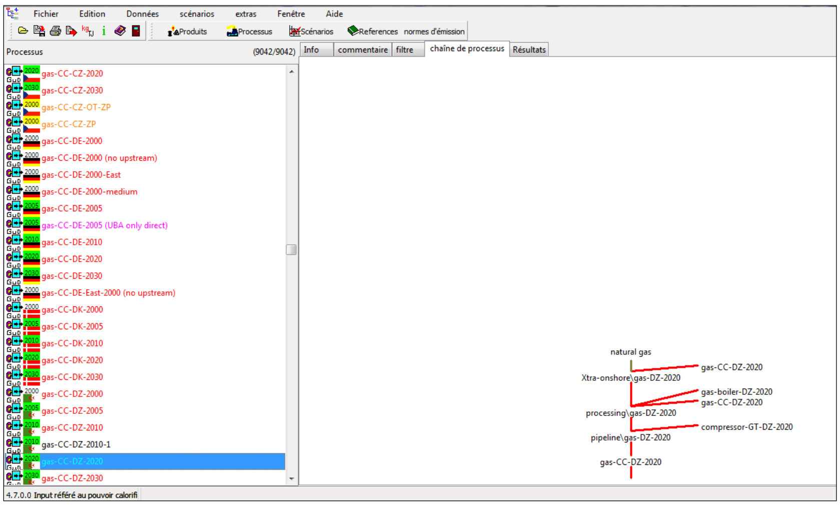

Figure 29. GEMIS 4.7 Software processes tree Window

3.2.3. Scenario and results

Represents the combination of demand (e.g. heat, electricity, transportation) and supply processes (e.g. heating system, power plant, and car). The scenario window also leads to a comparison between several processes (e.g., electricity generation processes in various countries). The classification of this category also follows specific filters.

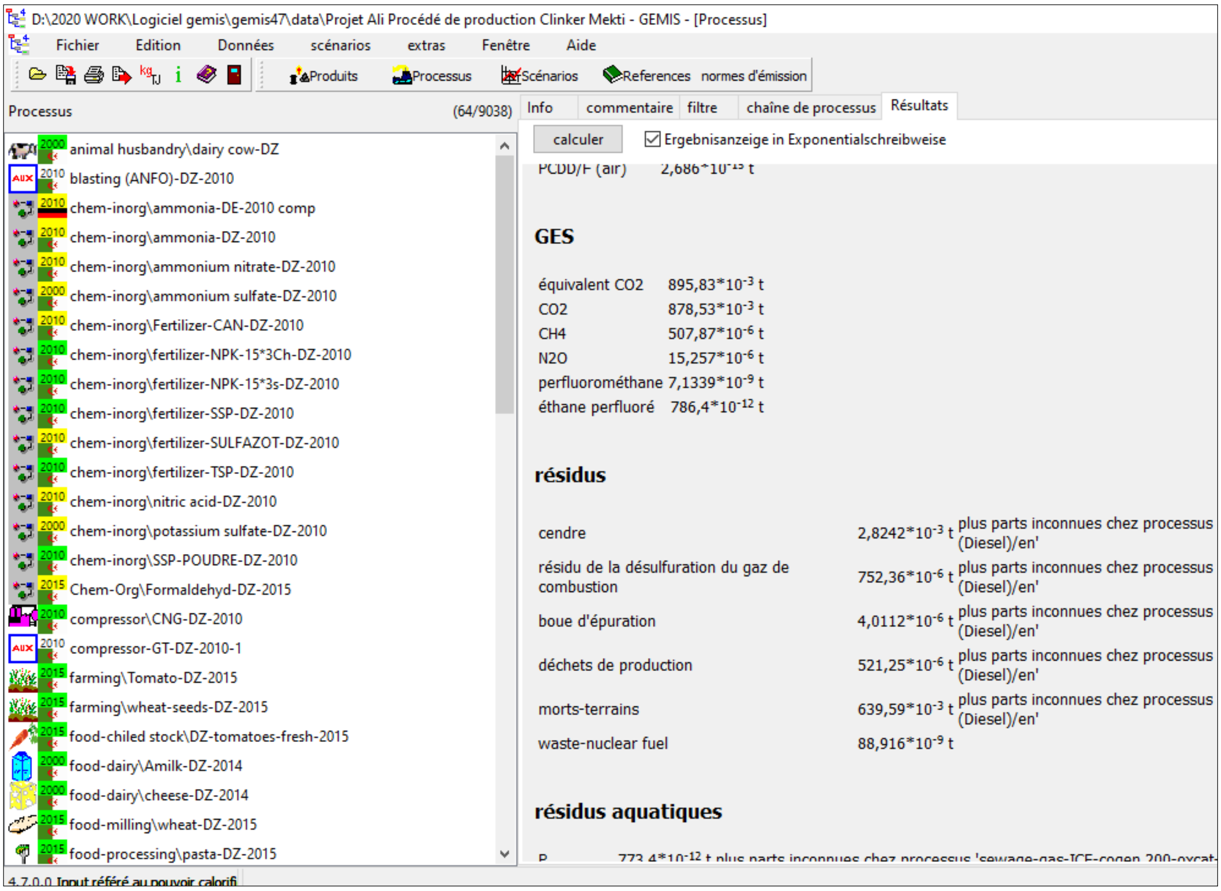

Figure 30. GEMIS 4.7 Results Window

The scenario category leads to the final phase of the LCA on GEMIS, which is represented by the "Result" window. It is also accessible directly from the main menu.

The results describe the impact of the modelled process on the environment based on several impacts: Air emissions, Greenhouse gases, Aquatic residues and other impacts.

The GEMIS modelling was a key operation to estimate the GHGs associated with each activity and the production of conversion factors, based on the database provided by Dr. Makhlouf.

Appendix 4. Production of input data for life cycle assessment.

3.1. Water Sector Case

The modelling the manufacture of water distribution network's pipelines was based on the following assumptions:

- The materials used for the pipeline is HDPE,
- Pipeline diameter, i.e., the smallest diameter is 63mm,
- The weight of one meter of pipeline for the chosen weight is 3.8kg.
- The total length of the network is not available. Therefore, the calculation is performed for 100 km.

Thus, the amount of CO_2 resulting from 100km of water pipeline is 148.2 $MtCO_2eq$.

3.2. Urban Planning Sector Case

3.2.1. Embodied Energy

Modelling of the generated emissions during the manufacture of building materials (embodied energy), and the consumption of electricity and natural gas (operational energy) has been established on GEMIS based on approximations necessary for the production of input data.

This the quantification was based on the weight of the materials used and the weight of the dwellings of each wilaya, calculated as follows;

1. Total number of dwellings in each wilaya for different types of housing programs.
2. Estimate of the proportion of materials used for each material (concrete, brick and steel), the calculation of proportions was based on the characteristics of each material (e.g., amount of steel in the reinforced concrete).
3. The total weight of the three materials represent the total weight of one dwelling for each type of program.
4. GEMIS modelling considers 1 tonne of a housing unite with the specific proportions (%) of each material.
5. The same calculation applies to individual houses (self-build) assuming an R+1 based on the quantitative reports provided by the architects and projects managers.

The conversion figures for each material are as follows:

- The conversion of reinforced concrete is based on its given density 350 kg/m^3 or 150 kg/m^3 in tonnes.
- The conversion of the brick is based on the surface of the brick used, where a double brick corresponds to 0.06m^2 and 3.5 kg per unit
- The conversion of steel is based on its proportion in reinforced concrete, which is on average 5%.

Table 41. Estimate of the total dwellings in the two wilayas of Algiers and Tipaza

Dwelling programs		Proportion		Units number (1999-2015)	
		Algiers	Tipaza	Algiers	Tipaza[36]
Public-rental		30%	48%	928 239.6	19593.6
Urban support housing (LSP-LPA, LV, LPP)	*Social renting **LSP***	16%	7%	3046.1	3046.1
	*Participatory **LPP***	11%	1%	247.0	247.0
	*Rent-to-own **LV***	4%	1%	329.3	329.3
Rural housing		39%	39%	120 6711.48	16053.6
Residential promotion		15%	1%	464 119.8	494.0
Total dwelling				2602693	151 961

The estimate of the total dwelling and the individual houses enabled an approximate estimation of the total quantity of the building material (**table 42**) which is supposed as the main components of both wilaya's real estate stock.

Table 42. Total building material quantity for housing programs in both wilayas.

Type	Unite weight	Total housing weight in Algiers	Total housing weight in Tipaza	Concrete		Bricks		Steel	
				10^6 tonne					
	10^6 tonne	10^6 tonne	10^6 tonne	Algiers	Tipaza	Algiers	Tipaza	Algiers	Tipaza
Typical dwelling unit	13.95	36.32	2.12	31.92	1.86	2.13	0.12	2.25	0.13
Individual house	60.11	36.20	0.08	9.01	0.02	16.62	0.04	10.56	0.02

Estimating the total number of building materials is important to quantify the total CO_2 emissions associated with housing (**table 43**), as the GEMIS modelling applies to 1 tonne of housing unite comprising an average of 88% concrete, 6% brick and 6% steel.

Table 43. CO_2 emissions resulting from building materials manufacturing in both wilayas.

Type	CO_2 emissions million $MtCO_2eq$		
	One tonne of a housing unit	Total housing units	
		Algiers	Tipaza
Typical dwelling unit	9.18E-01	33.34	$1.4*10^{-1}$
Individual house	7.35E-01	26.62	$1.03*10^{-3}$
Real estate stock		59.97	0.14

3.2.2. Operational Energy

3.2.2.1. Natural Gas

Emissions associated with natural gas and electricity use were estimated using data from the Ministry of Energy and Mines annual report (provided data for 2015). Accordingly, the

[36] The housing stock of Tipaza is estimated from the last census RGPH 2008

estimate of the actual household's natural gas' consumption has been performed prior the CO_2 quantification on GEMIS (**table 44**).

Table 44. Natural gas consumption by residents of the wilayas of Algiers and Tipaza

Naturel Gas	Total clients	Residential 97,8%	Low pressure	Residential consumption (90,9% LP)	Unit
Algiers	536 924	525 112	818	743	Mm^3
			32	29	MJ
Tipaza	63359.0	61965.1	85.0	77.3	Mm^3
			3.38	3.07	MJ

The combustion of this natural gas generates heat. The resulting amount of CO_2 is calculated based on the low calorific value LCV given by GEMIS (Makhlouf)[37] at 33.8012 MJ/m^3. Consequently, for 1MJ of burnt energy, the amount of CO_2 emitted equals 213.01 kg CO_2.

Table 45. CO_2 emissions associated with residential natural gas consumption

Natural Gas	Residential consumption	Unit	CO_2 Emission	Unit
Algiers	29	MJ	6.17	Tonnes
Tipaza	3.07		0.65	

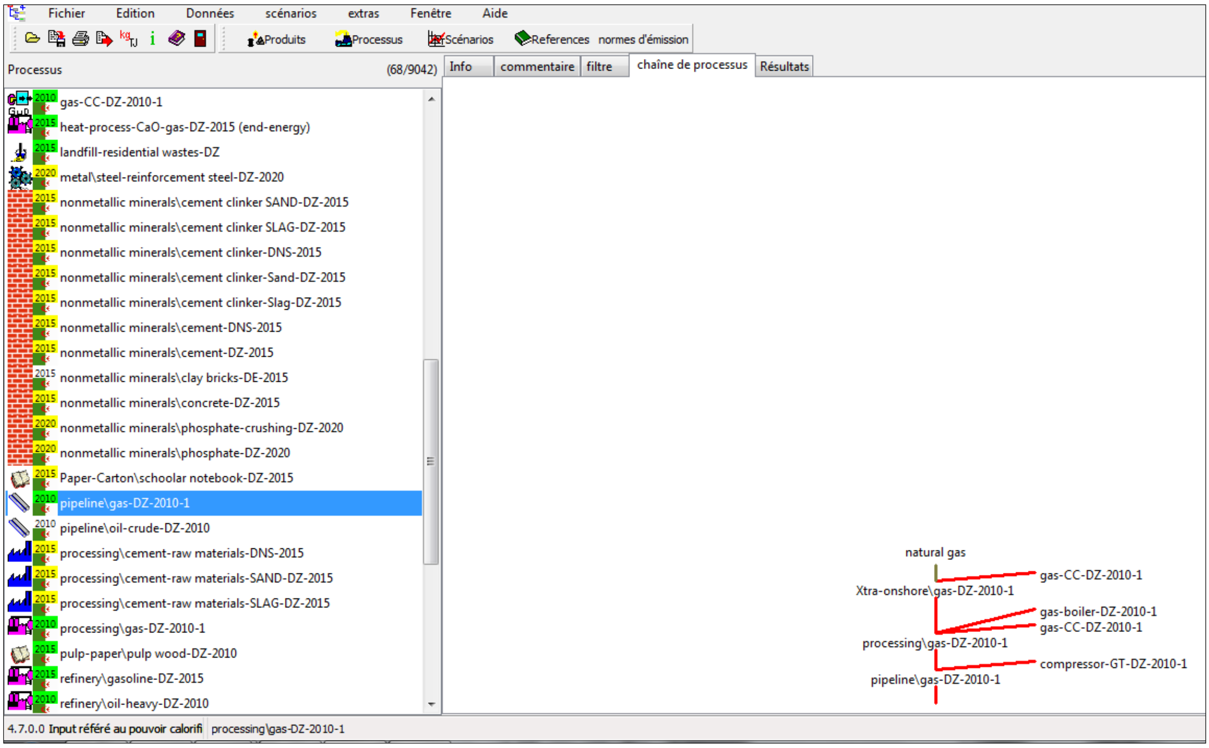

Figure 31. Process tree of the process delivering natural gas (1MJ)

[37] Database modelled using the Algerian industrial and manufacturing processes and energy forms, mainly oil and natural gas.

3.2.2.2. Electricity

Electricity in Algeria is generated from natural gas turbines (gas_CC). Therefore, the emissions associated with this form of energy result mainly from the transformation of natural gas. The resulting amount of CO_2 is calculated using the previous process (natural gas).

Table 46. Electricity consumption by the residents and the resulting CO_2 emission

Electricity	Total clients	Low voltage	Medium voltage	Residential (70 LV + 2% MV BT)	Unit	CO_2 Emission	Unit
Algiers	818 261	436.6	2 098.5	2148.06	**GWh**	0.81	**10^6tCO_2**
Tipaza	2 266 234	253.6	455.2	718.17		0.27	

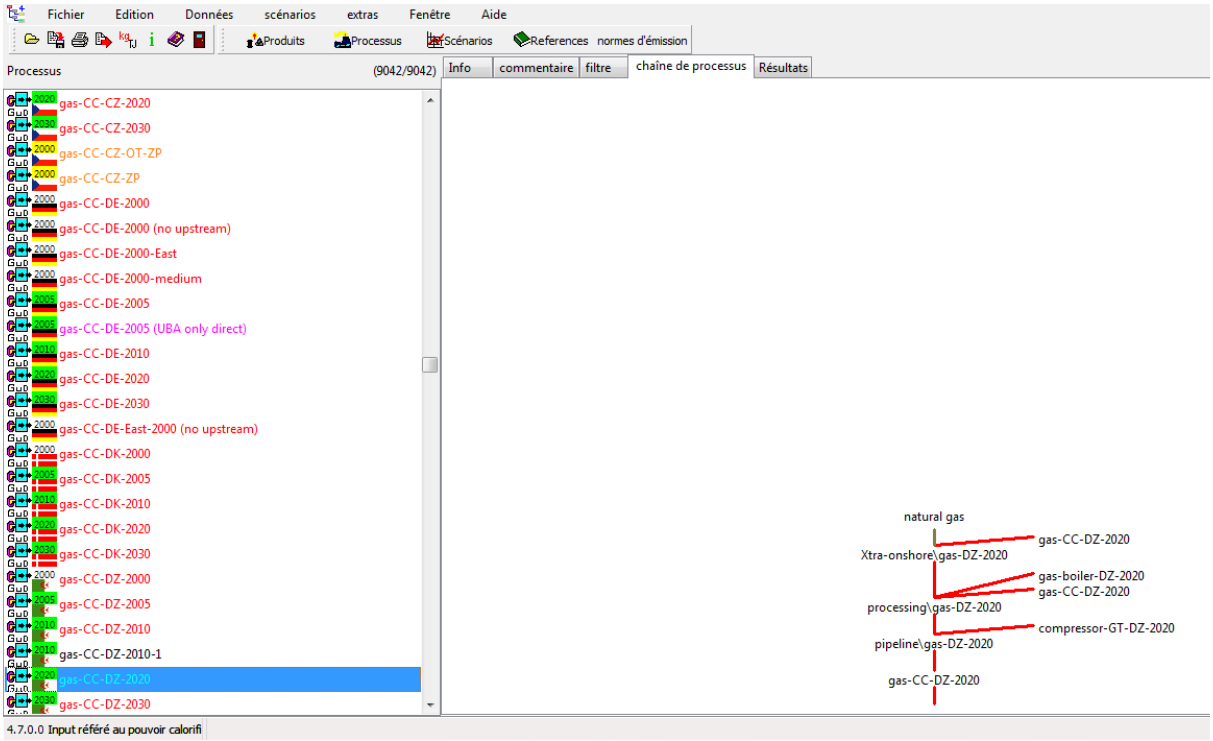

Figure 32. Process tree for electricity generation (Gaz-CC-DZ-2020) (1MJ).

Appendix 5. Areas estimation

5.1. Fishing Sector

The fishing area of each wilaya is not defined in the fishery statistics because the evolution of the marine biomass is not limited by each wilaya's administrative boundaries. However, the estimate of the area available for the production of natural resources (BC) reflects the marine and terrestrial fishing surfaces (lake-farming, dams), as well as the area exploited for aquaculture. Therefore, it was essential to define the marine area exploited by fishers.

5.1.1. Delimitation of fishing grounds

The delimitation of the fishing zone was based on Decree 84-181 defining the baselines for measuring the breadth of the maritime zones under national jurisdiction. This decree defines the coordinates of this baseline. Moreover, this line was used as a starting limit for the definition of the inshore, offshore and the total exclusive fishery zone.

Similarly, the length and the distribution of the different zones have been defined according to the national legal texts:

- Article 30 of the 01-11 Law (related to fisheries and aquaculture).
- Decree N°18-96 (Presidential Decree N°18-96 of 2 Rajab 1439 corresponding to 20 March 2018, establishing an exclusive economic zone off the coast of Algeria).
- Executive Decree N°96-121 (Executive Decree N°96-121 of 6 April 1996, outlining the conditions and modalities of Fisheries), and the Convention on Territorial Waters and the Contiguous Zone.

Thus, the study considers the following two fishing areas:

- The inshore fishery (coastal zone), which covers area less than 6 miles.
- The offshore fishing area between 6-12 miles.

The surfaces of each area are described in the table (**table 47**). The offshore area allocated to the aquaculture activity is also reported in the wilaya of Tipaza (Urban metabolism inventory).

Table 47. The fishing zone areas of the wilayas of Algiers and Tipaza

Zones	Algiers	Tipaza
Coastal fishing zone	55 877.26	126 098.9
Offshore fishing zone	253 618.24	229 503.2
Aquaculture area	[-]	1.2
Total fishing area	309 495.3	335 602.1

1. Urbanization Sector

The estimation of the urbanized area was based on two methods: the first derived from the data describing the housing stock of the two wilayas and the second from satellite images by the supervised classification method using satellite images from 2015. However, the second method considers all the infrastructures (industrial, commercial, other) of each wilaya, whereas the EF of energy and urbanized land considers the surface of residential infrastructures.

2.1. Estimation of the urbanized area using the first method

2.1.1. Dwellings Case

In this case, the study considers buildings of ten floors on average, with four dwellings per floor and an average surface of $60m^2$ for each dwelling unit. Furthermore, common spaces (stairs, elevator, and hallway) are included in this area as the tonnage estimate of materials considers all compartments of a building (infrastructure, superstructure). The estimate of this area excludes areas outside the buildings (e.g., play grounds, parking lot).

Similarly, the estimate of the area occupied by individual houses was based on the assumption that a single habitation occupies an average of $100m^2$. This area was multiplied by the cumulative number of building permits reported by the urban planning and construction bodies (DUAC) of both wilayas.

Appendix 6. Estimated Ecological Footprint of Fishing by species

The calculation of the fishing EF is based on the estimate of the biomass needed to sustain fisheries catches. Therefore, for each species the EF considers the trophic level of its prey species (TL-1), the landing statistics each species, and its specific yield factor according to the following equation:

Equation 6. Fishing grounds EF's equation

$$EF\_fishing(i) = \frac{PPRi}{PAi} \quad \text{Equation 6}$$

PAi: Average annual marine biomass available at the continental shelf level (this is the equivalent of the global average yield for agricultural products, or derived agri-food products ($tC.ha^{-1}.an^{-1}$)

PPRi is the specific requirement for species i, known as the required primary production ($tC.ha^{-1}$). The PPR is given by the following equation:

Equation 7. Primary production required equation

$$PPRi = \left[\frac{1}{9} * \frac{Pi*DR}{(TE)^{(TL-1)}}\right] * EQF \quad \text{Equation 7}$$

P*i*: Landing of the species i (tonnes);

DR: discard ratio 1.27 which stipulates that 0.27 tonnes of fish are caught accidentally for every 1 tonne of targeted fish;

TE: Energy transfer coefficient between prey species and its predator, estimated at 10%;

TL: Trophic level specific to each species;

EQF: Equivalence factor specific to the fishing grounds category 0.37 gha/ha;

1/9 is the carbon content of fish biomass, per wet unit weight.

Table 48. Example of Fishing EF Calculation by Species

Common name	Scientific name	CODE FAO	TL	Marine Production	PPR	EQF	EF_Fishing
[-]	[-]	[-]		[Tonnes]	[tC/ fish]	[gha/ ha]	[gha]
Round sardinella	*Sardinella aurita*	2088	3.4	1 829.26	35.45	0,37	5 644.8
Anchovy	*Engraulis encrasicolus*	2106	3.1	174.8	18.18		276.7
European eel	*Anguilla anguilla*	2203	3.5	0.12	47.8		0.48

Appendix 7. Estimated Ecological Footprint of Food by product

This section describes the EF of agricultural products included in the food sector. Livestock products from the same sector are described in **Appendix 2**.

7.1. Ecological Footprint per Product

Table 49. Detailed EF by crops for the wilaya of Algiers (2015)

Crops	Production (tonnes)	Ecological footprint (gha)
Other vegetables	60754	13761.9
Oranges	72390	6442.9
Flowering cabbage	26676	4765.1
Peaches	20241	3788.0
Grapes	29366	3111.7
Green cabbage	15016	2507.4
Apples	18286	2366.7
Green beans	8252	2120.3
Turnips	5971	1719.2
Potatoes	13713	1470.3
Carrots	6039	1038.2
Green beans	7239	1016.6
Lemons	10292	1000.6
Clementines	12376	937.8
Durum wheat	4245	892.5
Melons Watermelons	8160	737.1
Tomatoes	9365	705.1
Apricots	4692	725.6
Onions	2378	591.6
Mandarins	3197	536.8
Pears	8197	309.5
Peas	1270	298.8
Zucchini	3140	290.1
Plums	2378	288.9
Other fruits	1222	234.0
Artichokes	1438	232.7
Barley	422	211.6
Cucumbers	1189	551.7
Soft wheat	327	150.5
Pomelos	452	124.9
Peppers	1140	240.1
Garlic	240	96.1
Other vegetables (under greenhouse)	591	75.1

Oats	132	65.3
Fig trees for "Fresh" consumption	357	65.2
Olives	132	59.6
Olive (Oil)	253	53.8
Peppers	556	36.8
Fresh almonds	21	33.5
Eggplant	121	19.3
Carobs	6	17.4
Dry grape vine	0	3.8
Dry Almonds	0	2.5
Peanuts	0	0.8
Eggplant (greenhouse)	356	[-]
Eggplant (total)	356	[-]
Other vegetables (total)	713	[-]
Cherries	0	[-]
Quince	0	[-]
Cucumbers (greenhouse)	939	[-]
Cucumbers (total)	939	[-]
Zucchini (under greenhouse)	3845	[-]
Zucchini (total)	4784	[-]
Broad beans	0	[-]
Fig trees for consumption "Dry	0	[-]
Gesses and Guerfalas	0	[-]
Pomegranates	0	[-]
Dry beans	0	[-]
Green beans (under greenhouse)	8	[-]
Green beans (total)	8	[-]
Lentils	0	[-]
Corn	0	[-]
Melons Watermelons	0	[-]
Medlars	4258	[-]
Peppers (greenhouse)	973	[-]
Peppers (total)	5231	[-]
Chickpeas	0	[-]
Peas (dry)	0	[-]
Peppers (greenhouse)	2092	[-]
Peppers (total)	2092	[-]
Sorghum	0	[-]
Tobacco	0	[-]
Tomatoes (greenhouse)	18251	[-]
Tomatoes (total)	18251	[-]
Wine vine	0	[-]
TOTAL	**408 062**	**53697.5**

Table 50. Detailed EF by crops for the wilaya of Tipaza (2015)

Crops	Production (tonne)	Ecological footprint (gha)
Oranges	79324	124436.9
Durum wheat	44960	92295.8
Clementines	14143	75215.3
Cabbage flowers	23732	71481.6
Olive oil	49601	59225.9
Grapes	29372	43883.3
Peaches	14022	42832.4
Potatoes	78787	36505.9
Onions	17842	35229.3
Tomatoes	84851	34387.4
Melons Watermelons	48018	34157.0
Tomatoes	16771	31308.8
Apples	11520	30702.1
Cucumbers	28177	29799.0
Other vegetables	27491	25812.4
Soft wheat	10225	25380.5
Green beans	8270	23847.1
Zucchini	23613	22998.7
Apricots	12378	22547.4
Peppers	16353	21867.4
Barley	5239	18262.5
Carrots	4355	18025.5
Green cabbage	4975	16614.4
Green beans	4016	13980.2
Lemons	7486	11540.7
Peas	3600	10601.1
Plums	6679	7683.0
Artichokes	4482	7319.5
Pears	9781	6745.2
Olive trees	59637	6378.6
Fig trees for consumption "Dry	2300	4241.9
Almonds Dry	3335	3876.8
Carobs	446	3070.5
Garlic	511	2635.5
Mandarins	2238	2537.1
Eggplants	8791	1661.6
Peppers	6729	1169.7
Broad beans	551	1072.9
Oats	158	494.1
Chickpeas	180	331.1

Lentils	45	94.9
Dry peas	9	64.4
Dry beans	17	49.9
Others	40	33.4
Quinces	0	0.0
Pomelos	0	0.0
Fig trees for "Fresh" consumption	35080	[-]
Medlars	4779	[-]
Vine of vat	4668	[-]
Turnips	1202	[-]
Pomegranates	193	[-]
Fresh almonds	0	[-]
Peanuts	0	[-]
Others	0	[-]
Cherries	0	[-]
Gesses and Guerfalas	0	[-]
Corn	0	[-]
Sorghum	0	[-]
Tobacco	0	[-]
Triticale	0	[-]
Grapevine for dry grapes	0	[-]
TOTAL	**820 966**	**1 022 398.7**

Appendix 8. Comparison between the Ecological Footprint and the Biocapacity of both Wilayas and the Algerian case

The following table summarizes the data from the EF and BC of Algerian from the Global Footprint Network (GFN) data-platform (2022), as well as the calculation results for the two wilayas considered **(table 51)**.

Table 51. EF and BC (gha) of Algeria, and the wilayas of Algiers and Tipaza

Case	Metric	Built land	CO_2 Uptake	Cropland	Fishing grounds	Forest	Grazing land
Algeria	**Biocapacity (10^3 gha)**	1101.8	0	7791.6	316.6	1090.8	10 518
	%BC	5%	0%	**37%**	2%	5%	51%
	Total EF (10^3 gha)	1101.8	59 244.5	24786.7	625.9	6870.6	7223.3
	%EF	1%	**59%**	25%	1%	7%	7%
	BC-EF	0,00	-592 44.5	-16 995.4	-309.36	-5779.8	3 294.9
Algiers	**Biocapacity (gha)**	1730.4	0.0	13 203.2	108 787.7	34 521.7	8 907.8
	%BC	1%	0%	8%	**65%**	21%	5%
	Total EF (10^3 gha)	1730.4	61292.6	53.7	15.3	3.2	12.7
	%EF	0%	**100%**	0%	0%	0%	0%
	BC-EF (10^3 gha)	0.0	-61 292.6	- 40.5	93.5	312.6	-3.8
Tipaza	**Biocapacity totale (gha)**	155.6	0.0	44 267.2	117 964.2	43 209.1	17 646.5
	%BC	0%	0%	20%	**53%**	19%	8%
	Total EF (10^3 gha)	155.6	1 358.6	1022.4	275.03	0.9	14.7
	%EF	0%	**51%**	38%	10%	0%	1%
	BC-EF (10^3 gha)	0.0	-1358.6	-978.1	-157.06	42.4	2.9

Appendix 9. Urban waste

The following graphs (**figure 33, 34**) has been drawn based on each wilaya's municipalities annual municipal solid waste generation (MSW) reported by the MSW collection and transportation companies for the wilaya of Algiers and by the technical landfill center management company of the wilaya of Tipaza.

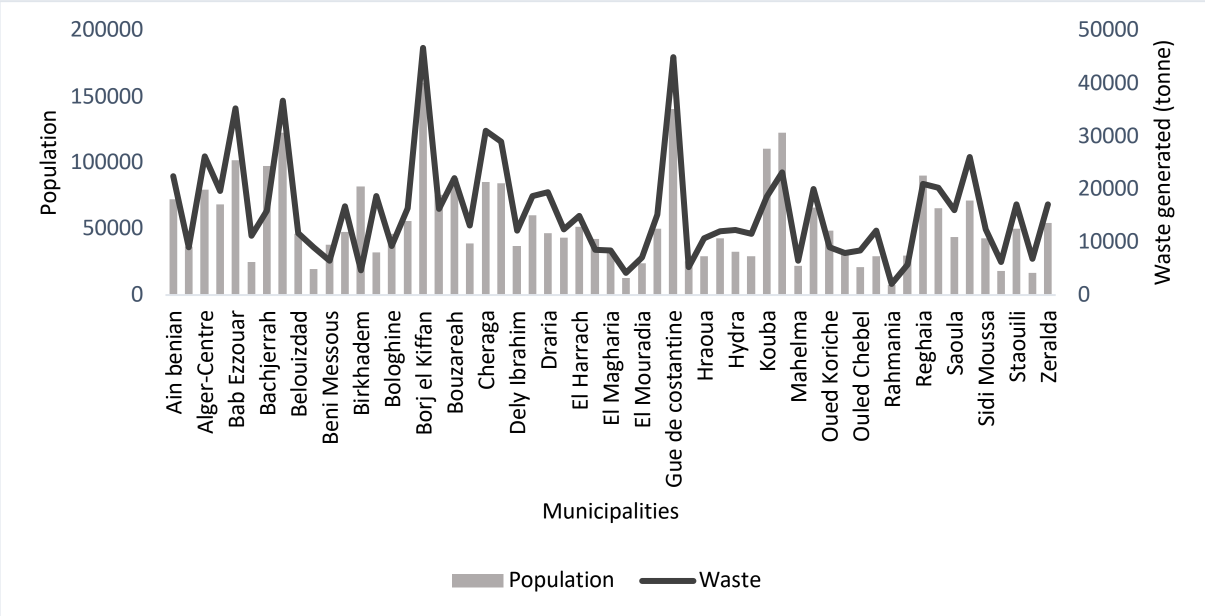

Figure 34. Municipal solid waste of Algiers Municipalities 2015

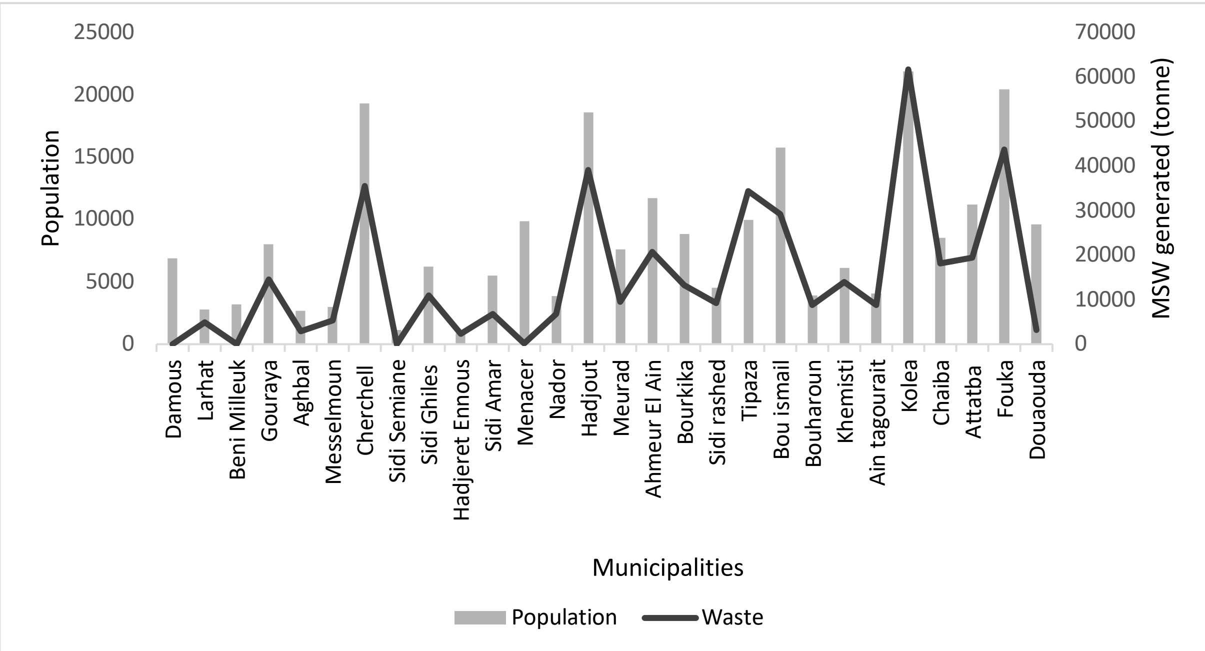

Figure 33. Municipal solid waste of Tipaza's Municipalities in 2015

Abstract

This thesis assesses the sustainability of Algeria's coastal cities based on several socio-economic activities, including fishing, agriculture and animal husbandry, forestry, urbanization, water consumption, and urban waste management, in coastal wilayas, i.e., Algiers and Tipaza, which are the main urban centers of anthropic activity.

Following a bottom-up approach of the ecological footprint, the model uses locally collected data and displays overshoot points for three components: material, energy, and built area. The main findings reveal that Algiers and Tipaza wilayas are facing an ecological deficit, which is more significant in the wilaya of Algiers (62 million gha). This result was anticipated for the wilaya of Algiers, selected precisely to demonstrate the effects of socio-economic activity intensity. Nevertheless, the wilaya of Tipaza, which was selected mainly for its significant natural assets, has a smaller deficit overall but more pronounced for the fishing activity.

Nevertheless, these data should be considered with caution, as this work was performed in a data-scarce context and required additional analysis, such as the life cycle analysis of each product consumed within the wilayas, thus, providing relevant knowledge to the limited literature on EF and life cycle assessment in Algeria. Furthermore, the contribution of this study lies in the information and diagnosis that the multilevel model supplies to decision-makers about the challenges of achieving sustainability in a given activity sector.

Most importantly, this study could also serve as the first document for the popularization of the ecological footprint concept and calculation in Algeria, as well as a baseline for public outreach programs on resource use and eco-responsibility.

Résumé

La présente thèse examine la durabilité des villes côtières algériennes en se basant sur plusieurs activités socio-économiques, notamment la pêche, l'agriculture et l'élevage, la foresterie, l'urbanisation, la consommation d'eau et la gestion des déchets urbains, au niveau des wilayas côtières, à savoir Alger et Tipaza, qui sont les principaux centres urbains d'activité anthropique.

Suivant une approche ascendante de l'empreinte écologique, le modèle utilise des données collectées localement et affiche des points de dépassement pour trois composantes : matière, énergie et surface bâtie. Les principaux résultats révèlent que les wilayas d'Alger et de Tipaza font face à un déficit écologique, qui est plus important dans le cas de la wilaya d'Alger (62 millions de gha). Ce résultat était anticipé pour la wilaya d'Alger, sélectionnée précisément pour démonter les effets de l'intensité des activités socio-économiques. Néanmoins, la wilaya de Tipaza qui a été sélectionné principalement pour ses atouts naturels importants connaît un déficit moins important globalement mais plus présent pour l'activité de pêche.

Par ailleurs, ces données devront être considéré avec précaution car ce travail a été réalisé dans un contexte de rareté des données et a nécessité des analyses complémentaires, telles que l'analyse du cycle de vie de chaque produit consommé au sein des wilayas, apportant ainsi des connaissances pertinentes à la littérature limitée sur l'EF et l'analyse du cycle de vie en Algérie.

La contribution de cette étude réside également dans l'information et le diagnostic que le modèle multiniveau fournit aux décideurs sur les défis de la durabilité dans un secteur d'activité donné. Plus important encore, cette étude pourrait également servir de premier document pour la vulgarisation du concept et du calcul de l'empreinte écologique en Algérie, ainsi que de base pour les programmes de sensibilisation du public sur l'utilisation des ressources et l'éco-responsabilité.

الملخص

تقيّم هذه الأطروحة استدامة المدن الساحلية الجزائرية بناءً على العديد من الأنشطة الاجتماعية والاقتصادية المتنوعة، بما في ذلك صيد الأسماك والزراعة وتربية الحيوانات والغابات التخطيط العمراني و إنتاج واستهلاك المياه وإدارة النفايات الحضرية في الولايات الساحلية (الجزائر وتيبازة) ، التي تعتبر من بين المراكز الحضرية الرئيسية للنشاط البشري.

اعتمادا على النهج التصاعدي للبصمة الإيكولوجية يرتكزالبرنامج المستعمل على البيانات المجمعة محليًا من طرف المؤسسات المسؤلة ويعرض نقاط التجاوز لثلاثة عناصر اساسية: المواد والطاقة والمنطقة المبنية. تكشف النتائج الرئيسية أن ولايتي الجزائر وتيبازة تواجهان عجزًا بيئيًا ، وهو أكثر أهمية في ولاية الجزائر (62 مليون ahg). كانت هذه النتيجة متوقعة لولاية الجزائر ،حيث تم اختيارها بالتحديد لإثبات آثار كثافة النشاط الاجتماعي والاقتصادي.
بالمقابل، فإن ولاية تيبازة ، التي تم اختيرت بالنسبة لاهمية وشساعة رصيدها البيئي ، تعاني من عجز أقل حدة (2 مليون ahg) بشكل عام ولكن أكثر وضوحًاو اكبر من ولاية الجزائر في نشاط الصيد.

ومع ذلك ، ينبغي النظر في هذه البيانات بحذر ، حيث تم تنفيذ هذا العمل في سياق ندرة البيانات وتطلب تحليلًا إضافيًا ، مثل تحليل دورة حياة كل منتوج مستهلك داخل الولايات ، وبالتالي ، توفير المعرفة ذات الصلة بالدرسات المحدودة حول البصمة الإيكولوجية و تقييم دورة حياة المنتوجات في الجزائر.

علاوة على ذلك ، تكمن مساهمة هذه الدراسة في المعلومات والتشخيص التي يوفرها النموذج متعدد المستويات لصانعي القرار حول تحديات تحقيق الاستدامة في قطاع النشطات التي تم التطرق اليها في هذه الدراسة.

الأهم من ذلك ، تهدف هذه الدراسة الأولية لتعميم مفهوم البصمة الإيكولوجية وتقيمها في الجزائر ، بالإضافة إلى استغلال البصمة الإيكولوجية كوسيلة للتوعية العامة بشأن استخدام الموارد والمسؤولية تجاه البيئية.