UNIVERSITY OF UDINE

Polytechnic Department of Engineering and Architecture

XXIX CYCLE OF DOCTORATE ON CIVIL ENGINEERING, ARCHITECTURE AND TERRITORY

PhD thesis

Integration of GIS and DSS: a methodology to evaluate low carbon strategies in a smart urban metabolism context

ACADEMIC DISCIPLINE: ICAR/06- SURVEYING AND MAPPING

PhD student
Alessia Movia

Supervisor
Prof. Fabio Crosilla

Co- Supervisors
Dott. Ing. Patrizia Simeoni
Dott. Ing. Alberto Beinat

Accademic Year 2016-2017

Dopotutto, domani è un altro giorno...

List of main paper

Paper I: Movia A., Beinat A., Crosilla F., 2015. Comparison of unsupervised vegetation classification methods from VHR images after shadows removal by innovative algorithms. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 40 (7W3), pp.1269.

I conducted the case study research, data collection, data integration, analysis, and together with my co-authors undertook the literature review and paper writing.

Paper II: Movia A., Beinat A., Crosilla F., 2016. Shadow detection and removal in RGB VHR images for land use unsupervised classification. ISPRS Journal of Photogrammetry and Remote Sensing. Vol. 119, September 2016, Pages 485–495. http://dx.doi.org/10.1016/j.isprsjprs.2016.05.004.

My contribution to this paper was planning the work, designing solution architecture, performing data collection, co-managing the research team, modeling, analysis, paper writing, and publishing.

Paper III: Movia A., Beinat A., Sandri T., 2016. Land use classification from VHR aerial images using invariant colour components and texture. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 41, pp.311. 2016.

My contribution to this paper was planning the work, performing data collection, analysis, paper writing, and publishing.

Contents

List of Figures

List of Tables

Sommario

Il metabolismo di un sistema urbano può essere esaminato cercando di sviluppare e comprendere i flussi energetici in ingresso e in uscita dalla città.

Accademici e ricercatori hanno utilizzato questo approccio al fine di analizzare diverse aree urbane e hanno recentemente esteso il quadro di analisi al di là dell'unità di città-regione al fine di utilizzare questo strumento nell'ambito del processo decisionale di pianificazione del territorio.

Questo percorso vuole definire una possibile metodologia e un esempio di approccio spaziale ad un'analisi di bilancio comunale di CO_{2eq}.

Si è sviluppato un Sistema di Supporto alle Decisioni multiobiettivo, con il fine di minimizzare l'impatto ambientale, sociale ed economico delle emissioni di CO_{2eq} su scala comunale.

Il Sistema di Supporto alle Decisioni ha previsto l'implementazione di alcuni scenari di analisi quali l'incentivazione dell'efficientamento energetico degli edifici residenziali ma anche industriali, l'aumento delle aree a verde, la produzione di energia elettrica in loco mediante impianto fotovoltaico, l'efficientamento del parco veicolare e infine una valida raccolta differenziata .

Il comune di Tavagnacco accoglie le sfide future in merito ai problemi ambientali, impegnandosi in un progetto pilota di valutazione delle emissioni di CO_{2eq}.

In un prossimo futuro si delinea un lavoro di confronto tra comuni che utilizzano metodi di abbattimento delle emissioni. Da questo confronto ci si aspetta di ottenere risultati che possano accreditare il metodo più conveniente dal punto di vista ambientale, economico e sociale, e quindi offrire delle basi per una valutazione sull'opportunità di miglioramento ed efficientamento energetico a livello comunale e sovracomunale.

Si auspica che i risultati di questo lavoro possano offrire elementi convincenti a supporto di un atteggiamento sempre più attento alle problematiche legate alla riduzione della CO_{2eq}.

Summary

An Urban Metabolism system can be examined evaluating the energy flows incoming and outgoing from the city.

Academics and researchers have utilized Urban Metabolism framework to analyze different urban areas and have begun to extend the framework beyond the city-region unit of analysis to inform related aspects of the Urban Metabolism: in this contest UM framework is a tool that can be useful the decision making planning.

This study wants to be an opportunity and an example of approach to environmental analysis of UM, from the point of view of CO_{2eq} emissions and absorptions.

A multi-objective Decision Support System is developed, with the aim of minimize the environmental, social and economic impacts of the CO_{2eq} emissions at the municipal level.

The Decision Support System has been implemented and few scenario analysis were developed: enhancement of energy efficiency of residential and industrial buildings, increase of green areas, production of electricity by means of photovoltaic installation on site, efficiency of the vehicle fleet and finally a proper recycling of wastes.

The municipality of Tavagnacco recognize this approach as a new perspective of analysis for a future comparison project with other municipalities.

From this comparison it is expected to get results that can accredit the most convenient method from the environmental, social and economic point of view, and offer the basis for the improvement of energy efficiency.

Results of this work can provide convincing evidence in support of an increasingly attitude to issues related to the CO_{2eq} reduction.

Chapter 1

Introduction

During the last years, human activities have modified the territory and consequently relevant changes have impact on climate and in atmospheric CO_2 concentration. They have led to the decline and extinction of animal and plant species; to make matters worse, these impacts have also the destructed the capacity to provide essential goods and services for human well-being [135].

In particular, cities and their development consumed resources of the ecosystems and this caused environmental consequences [44]: as their population density increase, pressure on the structure and function of ecosystem and their services became greater [14, 114, 123].

Climate change impacts and global environmental change are challenges for urban planners, and managers: to extend opportunities for the sustainable development of cities, researchers from multiple disciplines are studying the feedback, dynamics, and behavior of urban systems in the context of global changes.

Research have highlight a gap between the scientific knowledge and the planning process [35], moreover, environmental planning aims are often in conflict with social and economic development needs of countries and cities: carbon dioxide reduction requires an urgent change in urban policy making and planning that it is usually in conflict with the economic development.

Cities are dependent on access to resources and ecosystem functions outside their administrative boundaries and urban landscape features can significantly influence both energy and material flows [87, 91, 19, 101]; in particular urban centers grow in complex, unorganized, and sprawled way, this caused that low density cities have usually higher per capita energy consumption due to transportation sector [68].

Urban Metabolism (UM) has emerged as an important methodology and model for quantifying energy, water, carbon and pollutants fluxes; unfortunately, due to the heterogeneous nature of urban systems, the scale at which UM analysis are performed can influence modeling results, and subsequent policy decisions [1, 36, 44, 93].

The UM approach [23] in addition to that of Industrial Symbiosis (IS) [48], have provided a way of conceptualizing and assessing cities environmental impacts.

Using the urban metabolism framework will also create an accounting inventory of the actual energy used and its associated impacts in urban systems over short and long-term time scales. This will enable a more complete consideration of full economic, environmental and social effects of energy use that will inform better policy-making decisions. The variation in the units of analysis and metrics may provide a challenge in comparing different results of urban metabolisms between city, regions, countries so across different spatial scales as well as over time.

Urban metabolism has the potential to support urban planners in getting today's environmental, social and economic decisions for tomorrow, analyzing energy patterns and the causal process that govern them and developing environmental sustainability indicators for supporting sustainable and environmental assess [66, 123].

The objective of this research is to provide an integrated framework to support the planning and the decision making of future actions in the field of complex territorial systems, according to spatial quantitative elements regarding CO_2 fluxes.

1.1 Urban metabolism approach

The evolution of urban centers has caused a spatial segregation that takes place within cities. Urban areas are no longer only economic centers, but also social, cultural and ecological hearts towards sustainable development. Environmental problems are nowadays so crucial that globally cities face them in everyday life activities. Moreover, consumption is increasing the demand of resources, resulting in complex waste flows that require sustainable solutions [133].

During the 1960th for the first time, Wolman developed the concept of urban metabolism as a method for analyzing cities and communities through the quantification of inputs and outputs in response to the increasing problems in American cities air quality [157].

Recently, Urban Metabolism was defined as "the total sum of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" [87].

The urban metabolism approach defines urban ecosystems as dynamic, open systems of material fluxes and material storage on a range of spatial and temporal scales, where the urban ecosystem is considered as an urbanized area that includes various components such as urban vegetation, atmosphere, water, soil, human bodies, goods and buildings.

However, some authors [157, 35, 91, 19] attested that only individual organisms have a metabolism and cities are more like ecosystems rather an aggregation of various metabolisms. As ecologists support, an ecosystem embodies interactions among various individuals. So, the analogize of the city is better as an ecosystem than an organism [67]. Natural ecosystems are energy self-sufficient, instead the metabolic cycles of urban ecosystems are open and unsustainable

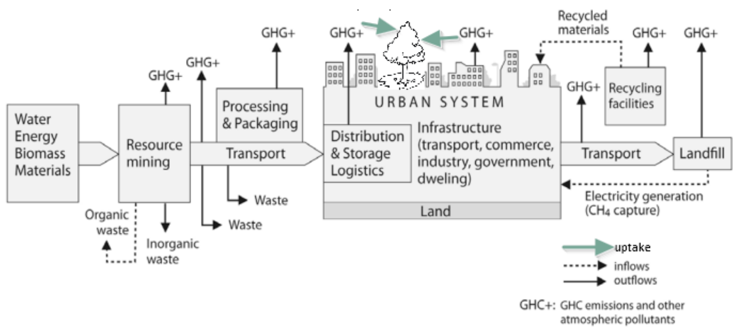

Figure 1.1: Urban metabolism framework. Source: [43]

because of high rate of material consumption and waste production [68, 123, 36].

The recognition that cities are like human, contributes to the understanding of the role of nature and interactions with the flow of resources needed with growth [123].

Urban metabolism concept considers a city as a system where flows of energy and materials are linked with the surrounding environment.

It is a multi-disciplinary and integrated platform that examines material and energy flows in cities as complex systems as they are shaped by various social, economic and environmental forces (Figure 1.1). In industrialized countries, the current patterns of urbanization generate a naturally inefficient metabolism which involves growing energy and resource consumption. The cross-scale impacts of this metabolic behavior actually decrease urban environmental quality and global sustainable development.

The concept of urban metabolism was explored through industrial ecology and general ecology, bio-physical sciences, political economy and urban planning studies, at a major scale with Life Cycle Assessment (LCA) and Material Flow Analysis (MFA) revealing in each case different aspects that can be integrated in the concept [123]. Cities have not historically been major units of analysis in Industrial Ecology, however LCA is achieving importance as analytical tool in assessing of the overall environmental impact of urban activities [14].

Urban Metabolism presents a framework to think about human systems and energy use, and issues of long term sustainability [157, 15, 87]

Urban transformations necessitate inside the city planning to integrate social, cultural, economy and also the environment of the city. As an extent, new strategies and mechanisms are the means necessary to promote flexibility in commuting, supply of power, equal water distribution and effective waste management system [36].

Literature described urban metabolism, in analogy of an human organism because process inside a city involved the intake of resources such as power, carbon, water and food and the release of heat, greenhouse-gases, pollutants, products and finally waste [157, 87].

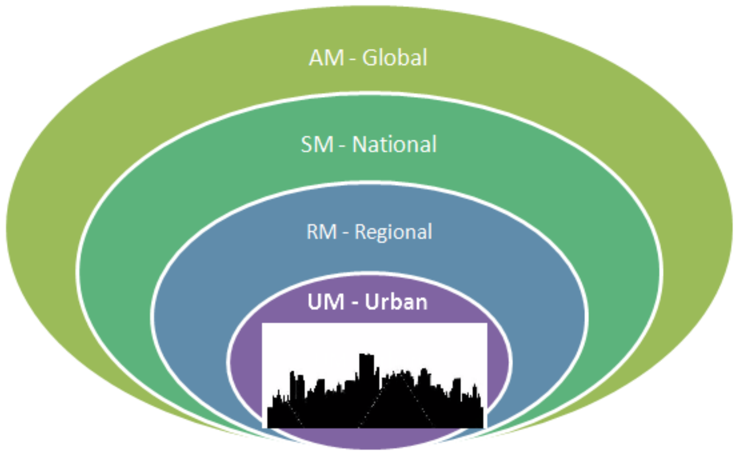

Figure 1.2: Scales of urban metabolism. Source: [160]

In comparison of most natural ecosystems that are self-maintaining, city cannot be autonomous and cannot work without energy, carbon etc, this caused a need to supply from the hinterland. Cities cannot be considered sustainable because they should necessary introduce resources from the surrounding areas.

The Urban Metabolism can be studied at different scales from individual households to regional and even global scales (Figure 1.2): HM-household metabolism, NM-neighborhood metabolism, UM-urban metabolism, RM-regional metabolism, SM-social metabolism, AM-anthroposphere metabolism. There is no one particular scale level of UM analysis that will generate meaningful results for urban planning and design aiming at optimizing resource flows [101, 160, 150]

Industrial ecologists attest that there are several tools to measure UM such as Material Flow Analysis (MFA), Emergy Analysis (EA) and Life Cycle Analysis (LCA); recently new methods were developed such as Input-Output Analysis (IOA) [123] and Ecological Network Analysis (ENA) [30, 31].

Princetl and Bunje [2009] have summarized the benefits of the urban metabolism framework:

- explicitly identifies system boundaries,
- enables a hierarchical research approach,
- accounts for system inputs and outputs,
- can be decomposed to study specific urban sectors,
- requires an analysis of policy and technology outcomes with regard to sustainability goals,
- is an adaptive approach to solutions and their consequences,

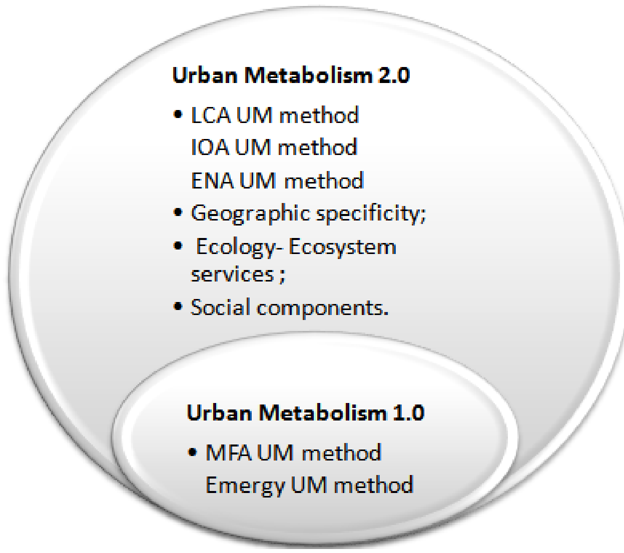

Figure 1.3: UM schools: differences on methodologies and components

- integrates social and biophysical sciences.

Nowadays it is recognized that there are two related, non-conflicting schools of Urban Metabolism (Figure 1.3) that include different methods of UM evaluation, in any case both require a great deal of data to compile complex models of resource flows within the urban system.

1.1.1 Urban Metabolism 1.0

The first school of urban metabolism concern two major approaches called Emergy and Material Flows Analysis (including quantitative analyses of life cycle costs, material flows and economic evaluation) that differ in information, calculation and metrics used. Even if the concept of Emergy was developed decades before the acceptance of more popular methodologies such as Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) and Industrial Symbiosis (IS).

First metabolism studies were focused on large metropolitan areas and were produced by engineers and ecologists during the 1970s.

The ecological approach to UM was deeply influenced by Odum's [1989] Emergy conceptualization of energy flows while the engineering approaches to UM studies, such as the Material flows one, involve, the quantification and assessment of energy and/or material flows (e.g. raw materials, nutrients and food) in standard mass units (e.g. kilograms, tons, joules) as they enter, accumulate and exit the urban system.

1.1.1.1 Emergy-based UM method

Emergys is defined as "the available solar energy used up directly and indirectly to make a product or service" and it is measured in solar emergy joules (seJ). Generally, Emergy method integrates energetic and material flows analyses of urban areas in order to understand cities in relation to their ecological resource bases [80, 122].

Emergy-based urban metabolism analyses have been conducted for specific cities: a first study of Miami's urban metabolism has been exploited by Zucchetto [1975] and economic, natural system and energy data were analyzed in a period that goes from 1950 to 1972.

The Emergy methodology has evolved, and new projects revealed new fields to explore in fact it has been used to study ecosystems, information flows, agriculture, landscape development, ecological engineering and material recycling even though its main applications derived especially from urban metabolism [22, 28].

Huang evaluated the Emergy flows of Taipei [77, 78] while many researchers focused on West Virginia [25], Zhang et al. [2009] analyzed Beijing and 5 other large Chinese cities.

Ascione et al. [2009] studied Rome metabolism and compared emergy indices of the city with national averages for the same ones, e.g. for emergy use per person, empower density, and emergy/GDP. The conclusion from the their study was that emergy intensity indicators and performance ratios confirmed Rome as a special resource attractor, but also confirmed the unsustainability of the metabolism, caused by the excess reliance on non-renewable and outside resources [10].

Recent research[153, 81] continue to use these kind of Urban Metabolism approach taking into account also social and economic factors.

Based on emergy synthesis and an urban spatial conceptual framework, Yang et al. [2014] elaborated seven emergy-based indicators to evaluate the sustainability of Xiamen metabolism using land use and socio-economic statistic data from 1987 to 2007. The results show a general improvement in socio-economic performance (emergy intensity, GDP emergy ratio, and emergy turnover ratio), but a deterioration in environmental one (emergy self-support ratio, emergy density, and waste density) during the considered period. Finally they attested that environment-oriented, society-oriented and cross-boundary-oriented metabolic strategies should be incorporated into future city development to support urban system sustainability [153].

During 2015 another study of Beijing city with the emergy analysis of the flows of materials, energy, and capital was performed. The indices of urban metabolism through emergy approach and land use change were calculated with the aim of analyze the relationship between urban metabolism and land use by correlation and regression analysis [81].

1.1.1.2 Material Flow Analysis (MFA) UM measurement method

During the 1990s, researches in the field of UM received major attention with the discover of new methodological tools like the Material Flow Analysis (MFA) that is an approach based on the availability of data-sets of urban materials flows [15].

The concept derives from the first law of thermodynamics that states that matter is neither created nor destroyed by any physical transformation process.

The goal of the MFA is to provide a system level understanding of how functions a city, a region or a nation . Early MFA focused on identifying material flows at the national level such as for Austria, Japan, Germany and Sweden.

This tool permits at the decision makers to analyze material flows within a given area, evaluating the relevance of these flows and controlling material flows to achieve management goals [73].

Material flows theories provides a framework to analyze how urban areas transform natural resources. The concept is particularly used in the engineering field where the emphasis is put on the flow of a specific material rather than through the entire systems [11].

Baccini and Brunner [1991] outline the general methodological steps of urban metabolism using Material Flow Analysis:

1. object study definition,
2. system description in space and time,
3. data acquisition,
4. material balances, dynamic mathematical modeling and scenario building,
5. interpretation such as comparisons of results.

Wackernagel and Rees [1996] examined the input-output flows of materials and energy of an urban area using a spatial ecological footprint analysis. The footprint expressed the amount of land required to meet the city's metabolic needs. Their calculations were based on five main categories of consumption: food, housing, transportation, consumer goods and services.

Folke et al. [1997] estimated with the MFA analysis, the consumption of wood, paper, fibers, and food, of 29 largest cities in Baltic Europe, and the GHG emissions sequestration. They conclude that the same cities appropriation of forests for assimilation of CO_2, exceeds the full sink capacity of the forests of the world by more than 10%.

Giradet [1992] utilized MFA in an ecological footprint analysis to calculate the resource used in London, from his studies estimated that the region's ecological footprint was 125 times the area occupied.

In 1999, Newman attested that it is possible to define that the aim of city's sustainability is: the reduction of the used of natural resources, the reduction of production of wastes, and the improving of the city's social livability. He applied his extended model (reported in Figure 1.4) for evaluating Sydney urban

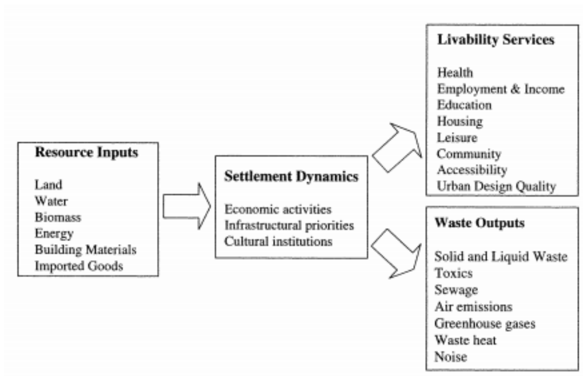

Figure 1.4: Extended metabolism model. Source: [112]

metabolism, integrating social and economic aspects of sustainability with the environmental one, and applying this model to a settlement of human activities in industrial areas, households and neighborhoods.

During 2000, two main MFA were exploited [41, 73]: the first one concern a review of the energy and material flows through the world's 25 largest cities, researchers attested that water fluxes comprised 90% of all material entering into the system and proved to be the most dominant flux across the cities. The research studied also fuel consumption among cities and revealed different variations in fuel type and quantity, this is a possible cause of the overall degradation of ecosystems.

The study also investigated food consumption, with limits caused by data availability and results indicated that the food consumption have an impact on nitrogen cycles in supplying agricultural areas and solid waste accumulation inside the city. .

Hendriks et al. [2000] analyzed two main areas of the central Europe: Vienna and the Swiss Lowlands while Warren-Rhodes and Koenig [2001] examined the metabolism of Hong Kong and they attested that there was an increasing of impacts on environment in the last century, with the transition from a manufacturing economy to a service based one.

Since MFA approach focus on materials, energetic aspects of the metabolism are not exploited limiting the scope and power of the analysis in understanding the UM of a system [71]. To fill this gap, Haberl et al. [2001] that proposed a new MFA method called Material Energy Flow Accounting (MEFA) to analyze input-output energy flows in Austria.

Sahely et al. [2003] studied the urban metabolism of Greater Toronto from 1987 to 1999; results demonstrated an increase of the rate of inputs and outputs-Inputs of water and electricity were estimated to increase marginally less than the rate of population growth, the outputs instead, were estimated to increase more slowly than the population, except for CO_2 emissions [134].

In the analysis of the UM of Paris and its region, Barles [2007] selected MFA

UM per capita	Sydney 1970	Vienna 1990	Sydney 1990	Hong Kong 1997	Greater Toronto 1999	Los Angeles 2000
Inputs						
Food (tons/year)	0.23	-	0.22	0.68	0.85	0.91
Water (tons/year)	144	147	180	138	183	258
Total Energy (GJ/year)	88	-	114	71	-	249
Outputs						
CO_2 (tons/year)	7.1	-	9.1	4.8	14.0	13.0
Solid waste (tons/year)	0.59	3	0.77	2.11	-	0.91
Wastewater (tons)	108	144	128	102	157	98

Table 1.1: Comparison of urban mass and energy balance between studies previously cited

to analyze flows at multiple scales – local, city and region – demonstrating that Paris is dependent on a wider area for its materials exploitation and, for its waste treatment, on the suburbs and surrounding regions [15, 16].

A study of Los Angeles has been conducted revealing a decline in inputs and outputs in the city for the years 1990 and 2000 [113]; Ngo and Pataki [2008] highlighted the higher food, water and energy imports of Los Angeles with respect to other 8 urban regions.

Niza [2009] studied Lisbon MFA where four variables were characterized and linked to material flows and were associated with the city: consumption of materials/products per category, performance of materials in the urban system per material category, material intensity of economic activities, and waste flows per treatment technology.

In Table 1.1 is reported a comparison of the results of the cited studies on MFA Urban Metabolism methods.

1.1.2 Urban Metabolism 2.0

The second generation of Urban Metabolism added spatial attributes, ecology and socio-economic components to the first methods of evaluation of Urban Metabolism (Figure 1.3). As Pincetl et al. [2012] attested, the biggest challenge to face in improving UM evaluation methods is that of integrate political, social, economic and geographic factors that govern the city and influence their Urban Metabolism.

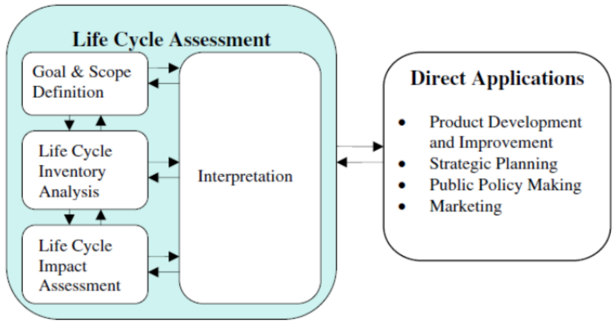

Figure 1.5: LCA framework. Source:[79]

1.1.2.1 Life Cycle Assessment (LCA) UM method

Life-Cycle Assessment (LCA) also defined as "cradle to grave" concept, is used to provide an assessment of a process from the beginning to the end including direct, indirect, and supply chain effects [34]. It is a young field of research related to energy requirements and pollution prevention of the 1960s and 1970s [131]: in fact LCA estimates and defines the environmental impacts of a product through its life cycle.

LCA is a quantitative tool that evaluates the direct component of interest, considering the inputs, outputs and sub-processes moving up the supply chain: evaluates the resource inputs and emissions outputs associated with economic activity in every sector of the economy [34, 77].

The general analysis begins with the development of a Life-Cycle Inventory (LCI) where all environmental inputs and outputs of the life time of the product until its end, are quantified (Figure 1.5). This is followed by a Life Cycle Impact Assessment (LCIA), it presents results that enables comparisons or further analysis [79].

Recently, Industrial Symbiosis (IS) and lean manufacturing contribute to developed the philosophy of LCA.

Industrial symbiosis is a practical application of the emerging discipline of industrial ecology.

Industrial Symbiosis is considered as the exchange of resources and energy flows between the companies: various industries and even farms exchange material and energy flows that otherwise would considered as waste. Thus it is important to create a system of links (industrial symbiosis) between different types of economic activity [48].

The application of IS can offer several benefits to the companies involved and make a significant contribution to sustainable development and the reduction of greenhouse gas (GHG).

Newman [1999] extended the model of urban metabolism in the field of industrial ecology and have promoted the concept of industrial symbiosis to improve the environmental performance of industrialized companies. Industries can examine their inputs of resources and outputs of waste while measuring their usual economic parameters: then, these data could be used to understand how useful solutions could be found such as the recycling of one industry's waste as an important resource for an closest one.

A case study for Kawasaki (Japan) has been exploited and from the results appeared evident economic and environmental benefits of exchange steel, chemicals and paper with other industries [146].

Lean manufacturing or Lean production, often called only Lean, instead, is a practice that considers the use of resources for any goal rather than the creation of value for the end customer.

Vinodh and Balaji [2011] reported a research where they had explained how to assess the leanness level of a manufacturing organization in which lean manufacturing principles are proposed: the leanness index has been computed and a decision support system has been developed.

Lean manufacturing goal is the preservation of the value of the final product, with less work.

It is a generic process management philosophy called Toyotism because it derived from the Toyota Production System (TPS) [105]. The Toyota system focused on reducing waste considering all the aspects of the production process using techniques and tools for the reduction of costs by eliminating the non-value activities and wastes. It presents a number of benefits such as a reduced delivery time, reduced inventory, better management and less rework.

However these tools requires greater spatial and temporal resolution, improved non-linear modeling capabilities, and consideration of socio-economic dimensions of urban environmental impacts [144, 107].

1.1.2.2 Input Output Analysis (IOA) UM method

This method mainly concerns natural and environmental categories such as water or carbon emission involved in domestic consumption.

Research have been developed in methodologies to downscale the national data for UM analysis caused by the lack of data-set at the appropriate scale [107].

IOA has recently become one of the favorite methods for modeling the consumption of natural resources and with increasingly accessible data on the different scales of the economies it is possible to compare the consumption around the world [142, 32].

Actually the IOA is a standard method to evaluate regional and local emissions and energy use for many economic consultants[138, 32]

Input–output analysis (IOA) can assess the direct and indirect energy consumption required to produce goods and services in the city based on interactions among sectors and exchanges with other economies [97].

The key of any input–output model is an input–output table (IOT) that represents the economic and material flows balance and provides an overview of all activities in a country or region.

Current input–output models for energy analysis can be distinguished into three categories [97]:

- monetary input–output table (MIOT) for energy expressed in monetary units,
- physical input–output table (PIOT) usually reported in energetic units,
- hybrid input–output table (HIOT) for energy, that is a mix of the two and it is in hybrid units.

During the years applications on monetary input–output model [151] and the physical input–output table model [152] were explored.

Liang et al. [2010] and Liang and Zhang [2011], proposed a hybrid physical input–output model for energy analysis (HPIOMEA) for the city of Suzhou in Jiangsu Province (China), based on the models of Xu et al. [2008] and of that of Xu and Zhang [2007]. The model calculated the energy resources in both energetic and mass units and air pollutants in mass units. They concluded that the input–output model is a useful tool because it is an expression of the industrial and energy structure, and technology development.

Beijing energy flows and economic sectors were analyzed using 9 economic input-output tables of years 1987, 1990, 1992, 1995, 1997, 2000, 2002, 2005, and 2007 [159] also carbon dioxide emissions of 2007 were studied [29]. Results of the researches showed that the energy consumption of Beijing increased from 38.85 million tonnes of coal equivalent (Mtce) to 206.2 Mtce over the past twenty years. In conclusion they attested that input-output approach can be a useful method for robust energy policy making.

1.1.2.3 Ecological Network Analysis (ENA) UM method

Ecological network analysis (ENA) emerges from the necessity to identify an integration of small interconnected entities [49].

ENA's concept and, the previous discussed, IOA are similar because both incorporated direct and indirect flows it derived from Leontief input– output model to analyze direct and indirect element flows through the ecosystem based on the interrelationships of components [85].

There have been studies using ENA to model urban systems as Network Metabolism, in which the mutual interactions and control relationships between urban sectors and system-wide properties of the city are addressed.

Chen and Chen [2012] developed a carbon flux model based on Network Environ Analysis (NEA) to examine urban metabolic processes and its emission (Figure 1.6). They examined the mutual interactions and control situation within the urban ecosystem of Vienna and they assessed the system-level properties of the city's carbon metabolism and finally regulatory strategies to minimize carbon emissions were identified. Their results suggested that indirect flows have a strong influence on carbon emissions values deriving from sectors such as: energy production and construction.

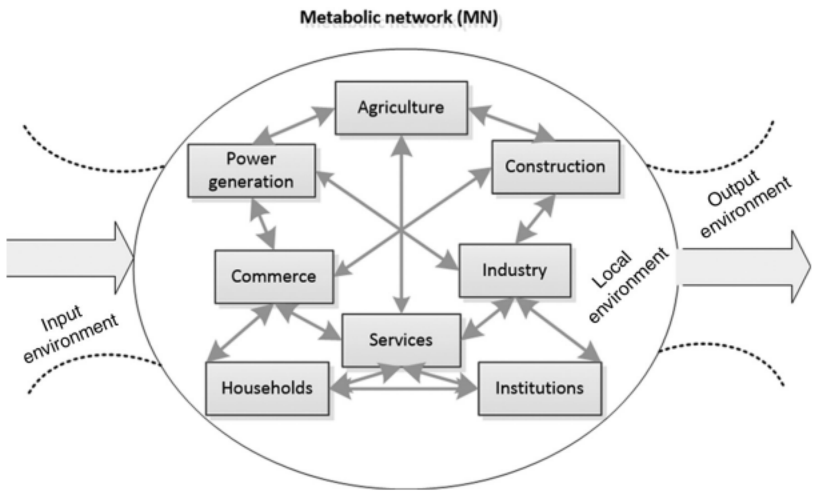

Figure 1.6: Example of Network Metabolism. Source: [30]

In comparison with the original LCA tracking, the application of NEA was better at revealing details giving particular importance on sustainable urban management[30].

1.2 The carbon cycle in the urban metabolism

Most of the gases presents in the Earth's atmosphere occur naturally, but human activity is actually increasing the concentrations of some of them in the atmosphere, in particular: carbon dioxide (CO_2), methane, nitrous oxide, and fluorinated gases. Among them, CO_2 is the GreenHouse Gas most commonly produced by human activities and it is responsible for 64% of the so called global warming: its concentration in the atmosphere is currently 40% higher than the period before industrialization.

Components of urban metabolism
Total electricity consumption
Consumption of heating and industrial fuels by each fuel type (e.g., natural gas, fuel oils, coal, LPG — includes fuels used in combined heat and power plants).
Total consumption of ground transportation fuels (gasoline, diesel, other) based on sales data.
Volume of jet fuel loaded onto planes at airports within the boundary of the city/urban region.
Volume of marine fuel loaded onto vessels at the city's port (if applicable).
Tonnage and composition of landfill waste (% food, garden, paper, wood, textiles, industrial, other/inert) from all sectors; and percentage of landfill methane that is captured
Tonnage of solid waste incinerated (if applicable)
Masses of steel, cement, and other materials or chemicals produced in the city causing non-energy related industrial process emissions.

Figure 1.7: Components of UM. Source: [92]

In these years, researches give particular attention to carbon cycle due to its considerable contribution to the global warming and notably is the contribution of the greenhouse gas emissions of human activities, especially urbanization [128].

Researches on the effects of CO_2 in the Urban Metabolism are recent: first of all, Pataki et al. [2006] evaluate the impact of fuel emissions in the carbon cycling in urban ecosystem with particularly attention to carbon balance.

Parshall et al. [2010] attested that local policy makers could benefit from a high-resolution inventory of energy consumption and related carbon dioxide to support climate or sustainability initiatives. They have found that a percentage between 37% and 86% of civil and industrial consumption of buildings and a percentage between 37% and 77% of on-road gasoline and diesel consumption occurs in urban areas.

To examine urban metabolic processes Chen and Chen [2012] developed a carbon flux model for the city of Vienna, based on Network Environ Analysis (NEA): they examined the interactions and control situation within the urban ecosystem and they assessed the system-level properties of the city's carbon metabolism.

The major impact on carbon emissions is given by energy production and construction. In comparison with the original life-cycle tracking, the application of NEA was considered better by the authors, at revealing many crucial details for informed sustainable urban management [30].

Kennedy et al. [2011] delineated a list of indicators that should be consider to calculate CO_2emissions (Figure 1.7).

During 2014 three main research discussed about the carbon cycle in the context of UM: the first developed an indicator for the metabolism of mega-cities [93]; the second investigated the spatial pattern of carbon emissions in Beijing to highlight the role of urban sprawl in changing the urban metabolism [159]; the third estimated the carbon flows in Nanjing that was largely affected by energy consumption, urbanization, rural activities [161].

Urban metabolism concept and it can contribute to everyday life: it can act as a tool for urban policy makers to know about risks regarding resource deterioration, [87] CO_2 emissions and waste production.

A sustainable city model could provide a good background for the adoption of new policies and strategies enabling cities to reduce their inputs from distant places, to decrease waste, and to achieve social equity [36]. In addition, awareness of the financial, social and environmental needs of the population is fundamental step to achieve a smart and sustainable city [31].

The policy and legislation framework can embody the urban metabolism concept in the definition of new objectives and guidelines. An environmental approach has to be totally integrated with socio-economic challenges and urban policies have to be updated.

The interdisciplinary approach is essential and in this cases, can clarify the effect that legislation has on urban flows and can contribute to more efficient management [148].

A difficult task to be achieved is the incorporation of different levels of action, due to the fact that individuals have to change their behavior. Government and local authorities have to be able to formulate regulations depending on needs, and private agencies have to be able to integrate new technologies such as computational modeling with the means to provide multi-disciplinary approaches as tools for both decision making and future scenarios evaluation [148].

The cooperation and coordination of administrations at different scales should promote the integration of local plans with national policies[122, 123].

Today many urban ecosystem models are available; Chen et al., [2014] conducted a study to count the existing studies of ecological modeling of urban systems and their results indicate that UM has been a rapidly growing field in the last decades; especially there is a trend of using more modeling techniques in the field of urban studies.

The existing models, though sharing the same assumption of treating cities as ecosystems, are highly different in terms of model structure, data used and purpose. It is difficult to classify them because they addressed different aspects and different components of the urban ecosystem.

Chen et al. [2013] divided them into top-down and bottom-up and integrated (bottom up and top-down) models, they also proposed a conceptual framework, reported in Figure 1.8 to develop for future UM researches.

Two papers are presented examining carbon dioxide (CO_2) emissions from the residential and transport sectors, and the energy impacts of an urban park. Vande Weghe and Kennedy [2007] examined CO_2 emissions from private transport and residential buildings in Toronto. They find that, over the entire region, emissions from private vehicles are similar with those from fuel use for building heating. In lower-density suburbs, GHG emissions tend to be higher, mostly due to private car use. Service industries are often viewed as less energy and material intensive compared with manufacturing and agricultural activities. Another common understanding of the ecosystem function of urban green spaces is that urban parks play an important role against negative environmental impacts of urban activities, including absorbing CO_2 emissions.

Two categories of bottom up models were land-use oriented models (Agent-based model, Cellular Automata, Market-based model, Gravity models) and infra-structured oriented models (*in situ* infra-structured model and Life-cycle infrastructure model).

Most of the top-down models, instead considered in UM researches are used for national and regional studies, and concern economic and biophysical processes such as industrial production, resource consumption, and carbon emissions. Top down models are divided into: Materials/energy-oriented models (MFA, Emergy, and Ecosystem services) and Structured oriented.

More attention is given to integrate the two types of models due to the fact that most practices of urban planning are carried out from the top-down, but cities dynamics arise from the bottom-up level. These hybrid models often include spatially dynamic data and sectorial data, they can be divided into:

- Multi-agent model: AUSTIME 'Assessment of Urban Sustainability Through Integrated Modeling and Exploration' and consists of six interrelated mod-

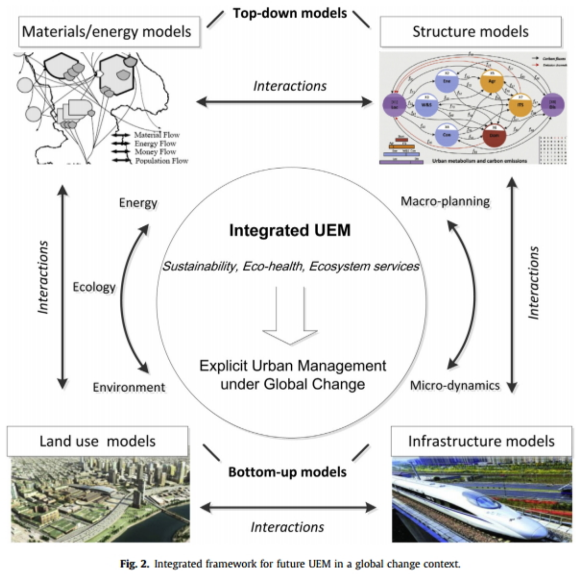

Figure 1.8: Integrated framework for new UM models. Source: [33]

els: water, carbon dioxide (CO_2), waste, economic, social and ecosystem health. The model of Daniell et al. [2005] links sustainability indicators with landscape planning and policy priorities for smart urban development,

- Activity-based model: iTEAM whose output are the impact of human activities on urban transport, land-use structure and resource consumption [5],
- Spatial Models: for instance Spatial energy model, Spatial carbon model, Emergy-GIS researched, the spatial distribution of energy consumption and intensity, spatial dynamics of carbon emissions, environmental impact and the changing sustainability [78, 37, 106],
- Decision Support Systems: BRIDGE model [35, 36] evaluated a spatial distribution of resources consumption and GHG emissions through GIS graphical data, surface characteristics, single building consumption and sectorial data.

1.3 UM and Sustainable development: a decision making perspective

Sustainable development is a desire for a better world or future. This desire could be interpreted as a goal to satisfy the needs of the present generation

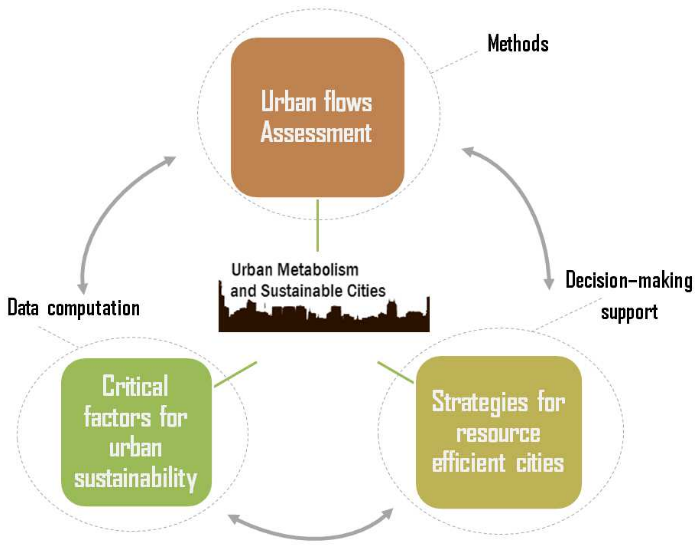

Figure 1.9: Decision Support System in an Urban Metabolism context. Source: [35]

without compromising those of future ones. Decisions involved in sustainable development include the objectives to:

- maximize resource use and energy efficient,
- reduce environmental impacts,
- reduce social impacts,
- promote the use of renewable and green technologies.

In sustainable development it is important to consider that planning is not only concerned with short term interventions as the long term considerations are more important due to the current global problems [72]. Policy and decision-making frameworks can give an opportunity to implement innovative and new strategies for efficient use of resources, with limitations due to critical factors (Figure 1.9).

1.3.1 Decision Support System (DSS)

It is not possible to give a precise definition of a Decision Support System (DSS) [88] that includes all the aspects of a DSS but it is possible to define it as a software-based system that supports business and organizational decision making activities interacting with both internal/external user and databases and implementing standardized or specific algorithms for problem solving [13, 24]. Three major characteristics define a DSS [6]:

- DSS are designed to facilitate decision processes,
- they should support automatic decisions,
- they should be able to answer quickly to any decision makers.

Holsapple and Whinston [1996] identified other typical DSS characteristics such as:

- includes the knowledge describing some aspects of the DSS,
- maintains all kinds of knowledge,
- has the ability of selecting any desired subset of knowledge,
- can interact directly with a decision maker or a participant in a decision.

DSS is also defined as an interactive system in a networked environment that helps a target group of managers. Managers usually want information presented in a format that effectively assist them in making decisions and need that this information are presented in a summarized format. The decision making process is considered like an horizontal flow [24]: the first stages called the "intelligence phase" concern problem classification and definition, the second phase, the "design phase", is associated with alternatives generation and evaluation, and finally the process ended by the alternative evaluation, selection, called the "choice phase" [127].

In literature it is possible to find five types of DSS:

- Data-Driven DSS: with these kind of DSS it is possible to have access and manipulate large databases o structured data. This type of DSS provide the highest level of decision support [13]. Examples are Geographic Information Systems (GIS) and Business Intelligence Systems (BIS),
- Model-Driven DSS: include systems that use accounting and financial models and optimization models. This type of DSS use data and parameters given by the decision makers to help them in analyzing any situation,
- Document-Driven DSS: They incorporate policies, procedures, product specifications, catalogs, historical documents and reports of meetings,
- Communications-Driven and Group DSS: include communications, collaboration and decision support technologies which permits to a group of decision makers to work together,
- Knowledge-Driven DSS: these DSS are person-computer systems with specialized problem-solving expertise.

The most used types of DSS are model and data driven while the most important processes supported by DSS are:

- storage, processing, and presentation of data,

- generation of possible alternative solutions to the problem,
- modeling and simulation of impacts,
- performance comparison of each alternative solution considered,
- analysis and evaluation of possible conflicts deriving from the different sets of preferences.

The problem is that some options may be good according to some criteria instead other options will be better against differing criteria. The Multi Criteria Decision Making (MCDM) technique can be used, since it provides solutions to the problems involving conflicting and multiple objectives.

A review of applications of MCDM to sustainable energy planning was given by Pohekar and Ramachandran [2004]. A framework of the MCDM method has two main phases:

- Phase I: the users decide on the objectives to cover their needs and determine their relative importance,
- Phase II: MCDM is used to judge the relative alternatives. This is done by determining scores for each alternative and for each objective.

1.3.2 Spatial Decision Support Systems (SDSS): GIS e DSS

Most of the information required for ecological evaluation and for environmental planning, is characterized by a spatial component. Consequently, a DSS linked to a GIS containing the relevant thematic layers is becoming a common strategy to deal with decision problems related to environmental planning [140, 61] (Figure 1.10).

In recent years, Geographic Information Systems (GIS) have been discovered as possible tools useful in a decision making process to support decisions in various topics making possible the integration of spatial data into the decision process [115].

The increase of GIS use, facilitates the efficient an processing spatial data, model accessibility, database maintenance and updating, and cartographic display of model results; in fact data . This can greatly enhance a DSS [7] in fact GIS systems can improve the realistic representation the problem.

Spatial Decision Support Systems (SDSS) are considered particular subset of DSS: data organization of decision models are similar to that of existing GIS [89, 61, Hills, Blaschke].

The coupling between GIS and DSS can be made in four different methods [pelizaro]:

- isolated applications:
- loose coupling: models are external to GIS, advantages are independent and flexible development but, on the contrary, users spend lot of time in data converting,

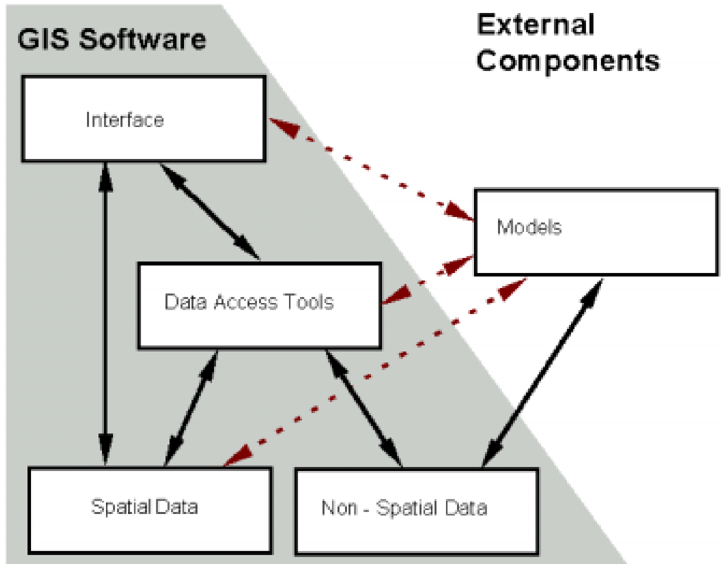

Figure 1.10: The SDSS as the integration of models with GIS. Source: [89]

- tight coupling: GIS users build up the model through the GIS software with the advantage that all the functions and data resources of GIS can be used,
- full integration, that can provide access to a user interface and data structure.

1.3.3 Modeling Smart Urban Metabolism through Decision Support System

The aspects of urban sustainability that can have an important role on climate change are the flows of carbon and energy produced by urbanized areas. For this reason, during the recent years the quantitative estimation of the urban metabolism components has increasingly attracted the attention of researchers from different fields. On the other hand, it has been well recognized that the structure and design of future urban development can significantly affect the flows of material and energy exchanged by an urban area with its surroundings.

The number of local authorities interested in addressing energy and climate concerns has been growing; at the same time that new funding sources for local energy efficiency measures are becoming available.

In the 2013, Blecic et al., developed a Decision Support System for low-carbon urban development. Their model for estimating future maps of CO_2 fluxes in urban areas is composed of four components: a Cellular Automata model for the simulation of urban land-use dynamics; a transportation model; a

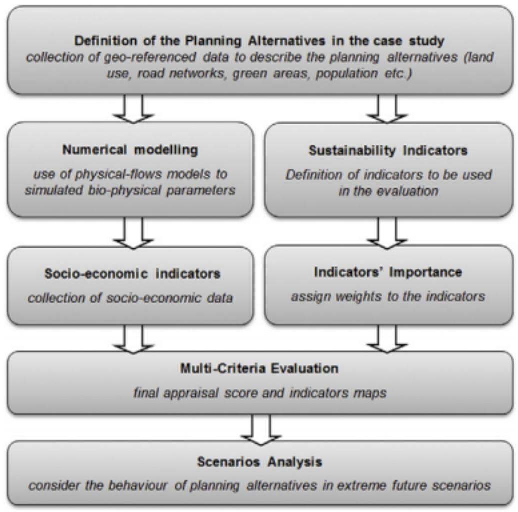

Figure 1.11: BRIDGE flowchart

Soil-Vegetation-Atmosphere Transfer model (SVAT) and finally a weather model (WRF) that includes the weather variables on carbon fluxes.

The authors had developed a software framework able to estimate carbon exchanges accounting for alternative scenarios which can influence urban development, and an application to the city of Florence has been applied[19].

Another example of SDSS is the LandCaRe-DSS, focused on the evaluation of different agricultural farm management adaptation strategies.

In comparison to other Decision Support Systems (DSS) the LandCaRe-DSS is dynamic, spatial oriented, interactive and extendable. Arampatzis et al. [2012] presented a decision support system (DSS) integrated in a geographical information system (Map Info- GIS) for the analysis and evaluation of different transport policies. The DSS works on three levels: performing the transport network analysis, assessing the energy consumption and pollutant emissions calculating them with the methodology developed by the CORINAIR working group and evaluating the several policies selected.

Brauckmann and Mayr [2013] illustrated the RegioProjektCheck, a new instrument derived from an existing decision-support-systems realized with a set of toolboxes in a Geographic Information System (GIS) in order to support sustainable strategic planning [38].

The Integrated Spatial Assessment (ISA) approach was applied to the new City Plan of the municipality of Montecorvino Rovella in the Province of Salerno.

Inside the BRIDGE (sustainaBle uRban planning Decision support accountinG for urban mEtabolism) project, Five European cities have been selected as case studies to evaluate the sustainability of urban planning interventions, in order to make it possible a MCDM has been adopted in BRIDGE DSS (Figure

1.11). This method is conducted through seven-step procedure: selection of the objectives and the criteria; develop of measurement scales for the criteria; develop of alternatives; define the objectives and criterion's weights; evaluation the performance of the alternatives; aggregation of scores; analysis of the results and guiding decisions. The DSS was used to evaluate how the planning alternatives proposed modified the urban metabolism, for energy, water, carbon and pollutants fluxes [35, 36].

1.4 Normative background

This paragraphs will focus on normative and laws for emission reduction considering various scopes, i.e. on an International, European and National (Italian) and regional Italian scale.

Legislation focuses on immissions, concentrations and emissions on pollutants. Immission depends on site-specific conditions, which in turns relate emissions and concentrations. The legislator acts at these two levels (emissions and concentrations) defining limits and standards for major pollutants as those previously outlined, while authorization for emissions on particular environment (immission) are allowed depending on each specific case (Environmental Impact Assessment, EIA). According to the latest findings of the Intergovernmental Panel on Climate Change (IPCC), climate change will bring severe, pervasive and irreversible impacts on all the world's people and ecosystems. Limiting dangerous rises in global average temperature to below 2°C compared with pre-industrial levels (the below 2°C objective) will require substantial and sustained reductions in greenhouse gas emissions by all countries.

1.4.1 International Legislation

International Legislation Climate change, and the link between GHG_s emissions and climate change, is the most well-known debated among the various environmental impacts. On an international scale, the most relevant normative related to GHG_s emissions has been the Kyoto Protocol of 1997 that was recently confirmed with the Paris Agreement of 2015.

1.4.1.1 Kyoto Protocol

Kyoto protocol represents the first international agreement on climate change based on the premise that global warming exists and man-made CO_2 emissions have caused it. It was signed by over 160 countries during the COP3 conference of the UN on Climate Change and Global Warming. The agreement consisted in reducing GHG_s emissions (CO_2 and other five pollutants, such as CO and methane) that were not mentioned in the previous Montreal Protocol of 1987 of a global 5,2% if compared to 1990's level, in particular the result should be achieved before 2012. Local reduction objectives have been selected for each of the ratifying countries. EU (and Italy) ratified the agreement on the 31st of May

2005, aiming to reduce GHG_s emission by 6.5% (Italy) even if such reduction, in 2010, was far to be achieved for Italy.

1.4.1.2 Bali, Doha and Copenhagen conferences

Bali conference of 2007 represented the first step for defining the "post-Kyoto". It has been impossible to define a new set of rules or finding prescriptions on GHG_s reduction, so the main output of the conferences was limited to a "road map" to new formal negotiations to be held in 2012. The Copenhagen Conference (2009) instead, even presenting a similar goal defining new rules and prescription to reach Kyoto's target.

1.4.1.3 Paris agreement

During the 2015 United Nations Climate Change Conference also called COP 21 was held in Paris, that conference negotiated the Paris Agreement, a global accord on the reduction of climate change. The output of the conference was the Paris Protocol that was pointed out in order to promote collective action in line with the IPCC's findings. The Paris Protocol must reach the following objectives:

- the long term goal is the reduction of global emissions by at least 60% below 2010 levels by 2050,
- provide for a global review, to be conducted every five years, to reach the ambition of these mitigation commitments consistent with the latest science,
- reach transparency and accountability in order to be able to assess whether emissions reduction targets and related commitments have been met,
- encourage climate-resilient sustainable development by promoting international cooperation and supporting policies that decrease vulnerability and improve countries capacity to adapt to the impacts of climate change.

All G20 nations, representing around 75% of global emissions, as well as other high and middle-income countries are expected to ratify the Protocol until 2020.

The Protocol should enter into force as soon as countries accounting for more than 40 Gt of CO_2 equivalent emissions in 2015 have deposited their instrument of ratification and this represents approximately 80% of current global emissions.

1.4.2 European Legislation

International efforts have been translated on a European level by the development of specific regulation, in which the so-called "20/20/20 Directive" represents the main output (December 2008). The European 2020 strategy aims at a growth that is: smart, through more effective investment in education, research and innovation; sustainable, thanks to the decisive choice in favor of an economy with low CO_2 emissions; and solidarity, that is focused on creating jobs and reducing poverty. Such directive imposed to the member states the adoption of measures in order to reduce GHG_s emissions by 20% (or even 30%, if the conditions are right) compared to the 1990 levels, increasing energy production from renewable sources up to 20%, and reducing energy consumption by 20%, and all these objectives should be achieved before 2020. European legislation, while providing country's guidelines in order to achieve the European Community goals, has also focused on emission and concentrations of pollutants, particularly, the EU directive 2008/50/CE identifies the objectives of air quality, defining methods for evaluating, maintaining and improving the latter, promoting collaboration among EU countries. The directive focus also on air quality limits on concentrations of SO_x, NO_x, CO, Pb, PM_{10} and $PM_{2.5}$, As, Cd, Benzene, Benzapyrene and Ozone.

Regarding pollutants emissions, EU directive 96/61/CE, later updated by the 2008/01/CE, defined a range of activities which require particular authorization process (Integrated Environmental Authorization) and whose emission limits, regarding specific pollutants, have to be defined by single States.

Activities subjected to the IPCC directive are, for example, energy industries (energy production, refineries, coke and coal gassification ovens), metals production and processing, mineral industries (cement clinker, asbestos, glass, ceramics), chemical industries (organic and inorganic), waste management and other activities (pulp and timber industries and others), with some of the activities to be subjected only over pre-defined throughput threshold.

Furthermore Europe has a policy framework for energy and climate for 2030, as well as an energy security strategy. Meanwhile, an integrated energy market for all EU countries is closer than ever before. The identify objectives of this recent strategy concern:

- pool resources, connect networks and unite the EU's power when negotiating with non EU countries,
- diversify energy sources – so Europe can quickly switch to other supply channels if the financial or political cost of importing from the East becomes too high,
- help EU countries become less dependent on energy imports,
- reduce Europe's energy use by 27% or greater by 2030,
- build on the EU's target of emitting at least 40% less greenhouse gases by 2030,
- make the EU the world number one in renewable energy and lead the fight against global warming.

1.4.3 Italian Regulation

Italian legislation received EU directives, but detailed actions in order to achieve the tree main objectives of the previously assessed directive. Specific legislation has been developed for assessing:

- GHG_s emissions and immissions,
- renewable energy production,
- energy efficiency.

Referring to air quality regulation, limits of the Italian decree n.155 of 13/08/2010 to the previously described European directive. IPCC and National legislation regulated $GHG_s$to identify emission limits for each of the main sectors. Such step was taken by the Italian D.Lgs.152/2006 ("Testo Unico Ambientale") updates, which, among the consistent amount of normative which is there reported limits for toxicants emission (NOx, SOx, VOCs, ecc.).

At the national level, international and European policies have been addressed mechanisms aiming to faster achieve the goals of renewable energy, production efficiency and greenhouse gases reduction. National incentives on renewable energy productions refers to power production, different schemes of incentives have been developed such as:

- CIP6 mechanisms, which represented the first system for renewable energy based on fixed incentives schemes,
- Green Certificates, evolution of the CIP6 mechanisms but considering schemes,
- Renewable Energy Certificate System (RECS),
- In tariffs for photovoltaic plants production.

The emission reduction certificates were first introduced at European level, from Kyoto protocol, by the directive CE/87/2003 and the emission trading scheme (ETS) has been then regulated in Italy by D.Lgs.273 of 12/11/2004. The green certificates mechanism, in Italian "Certificati Verdi", consists in a system stock-market. Fossil fuel energy users, above a certain threshold, are obliged to produce their energy by means of renewable sources, creating a "demand" for green energy.

Auctioning their quotas, Member States should appoint a " National Manager", the Auctioneer. The GSE (Gestore Servizi Energetici) is the Lead Manager of the Italian emission allowances on the centralized platform at European level (Legislative Decree 30/2013 subsequently amended by Legislative Decree 111/2015). The Italian auctioneer regulates the national market, and represents the point of reference for the price of the certificates.

While in January 2011, GSE communicated the average price of CV as 87,38 €/MWh, during the 2015 the average price has been substantially reduced to € 51.69 MWh, as defined by the Authority for electricity gas and water system the 28 January 2016.

The withdrawal price for green certificates issued for generation from renewable sources for the year 2015 is equal to € 100.08/hp , equal to 78 % of the difference between the value of 180.00 €/MWh and the annual average recorded in 2015, the electricity selling price referred to above; the withdrawal price of the released for cogeneration combined with district heating production of the year 2015 is equal to € 84.34, in accordance with the provisions of Article 25, paragraph 4 of the Decree. n. 28 of 3 March 2011.

This system is not compatible with other forms of incentives or other capital expenditures.

1.4.4 Regional normative

The Friuli Venezia Giulia region is part of the "Central Europe 2020 Program" whose strategy framework consider four priority axis. Among these, one axis has the main objective of cooperating on energy to reduce carbon footprint in Central Europe, in order to reach this aim it is necessary to support the shift to a low-carbon economy in all sectors: supporting energy efficiency and renewable energy use in public infrastructures, and promoting low-carbon strategies in particular urban areas, including the promotion of sustainable urban mobility and mitigation relevant adaptation measures.

Furthermore, with the EC decision (2015) 4814 of 14/07/2015, the European Commission has approved the "Operational Program of the European Regional Development Fund" 2014-2020 "Investments for growth and jobs" of the Friuli Venezia Giulia region, promoting again a transition to low-carbon economy:

- promoting the production and distribution of energy from renewable sources,
- promoting energy efficiency and the use of renewable energy in enterprises,
- supporting energy efficiency, intelligent management energy and renewable energy use in public infrastructure, including public buildings, and in the housing sector,
- developing and implementing smart distribution systems operating at low and medium voltage,
- promoting low-carbon strategies for for all types of territories, in particular urban areas, including the promotion of multi-modal urban mobility sustainable and relevant adaptation measures and mitigation,
- promoting research and innovation in the field of low-carbon technologies and their adoption,
- promoting the use of combined heat and high output power based on supply useful heat.

1.4.5 Municipality acts and the"Covenant of Mayors"

The Covenant of Mayors for Climate and Energy addresses the synergies between the mitigation and adaptation to reduce the adverse impacts of climate change. The ”Action Plan for Sustainable Energy 2012-2020” (PAES) is the tool identified by the ”Covenant of Mayors” Program of the European Commission to be able to start ”from below” a series of interventions aimed to reduce by more than 20% its greenhouse gas emissions through local policies that improve energy efficiency, increase the use of renewable energy sources and encourage energy saving and rational use of energy. The Mayors share a common vision towards 2050 to:

- de-carbonised territories, thus contributing to keeping average global warming well below 2°C above pre-industrial levels, in line with the international climate agreement reached at COP 21 in Paris in December 2015,
- more resilient territories, thus preparing for the unavoidable adverse impacts of climate change,
- universal access to secure, sustainable and affordable energy services for all, thus enhancing quality of life and improving energy security. To achieve these aims a set of actions were defined,
- reducing CO_2 (and possibly other greenhouse gas) emissions on the territory of our municipalities by at least 40% by 2030, namely through improved energy efficiency and the greater use of renewable energy sources,
- increasing our resilience by adapting to the impacts of climate change,
- sharing our vision, results, experience and know-how with fellow local and regional authorities within the EU and beyond through direct cooperation and peer-to-peer exchange, namely in the context of the Global Covenant of Mayors.

The sectors of climate change mitigation were Energy, Transport, Waste and Urban planning. Actually, in Italy, 1430 municipalities have signed the Covenant of Mayors.

Chapter 2

The general method

The database component within a decision support system (DSS) mostly deals with non-spatial data collection, retrieval, management, and analysis; Figure 2.1 illustrates the components of each of them. GIS can be considered to be composed of three major components: a database, a user interface, and spatial data creation, analysis, and presentation capabilities [139]. From the combination of DSS and GIS, the Spatial Decision Support Systems (SDSS) have been evolved.

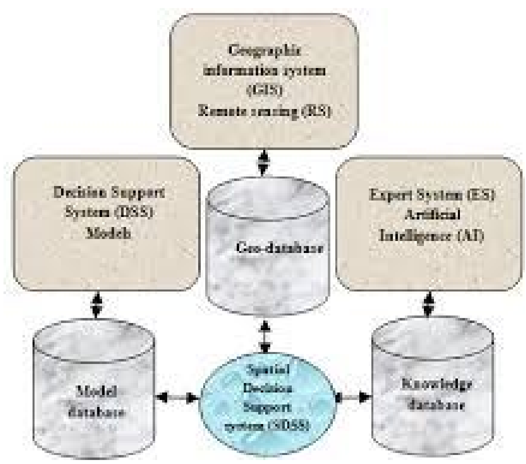

Figure 2.1: GIS and DSS components. Source: [129]

The general structure of a DSS consists of three main steps, reported in Figure 2.2 where it is introduced a new one due to the introduction of the spatial attribute:

- Intelligence or Investigative Phase- problem classification/definition,
- Design Phase- alternative generation/evaluation,

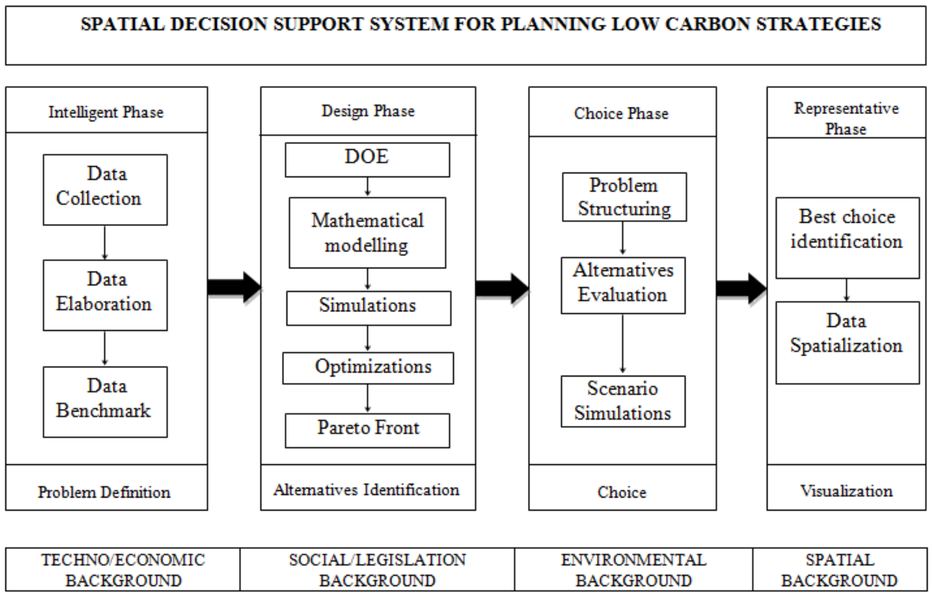

Figure 2.2: General structure of a SDSS

- Choice Phase- alternatives negotiation/selection and action determination,
- Representative Phase- spatial visualization of the choice.

The decision making process moves from the Intelligent Phase where can be found preliminary stages of data collection, elaboration and benchmark to a "creative" phase of alternative generation, which consider mathematical multi-objective spatial decision support system. The last phases concerns the choice among different alternatives and the representation of the best solutions available; the choice phase objective is to identify the best solution among a range of alternatives.

2.1 Intelligent phase

The analytic o intelligent phase is the preliminary step; as remark in Figure 2.3 it consists on data collection and evaluation with the purpose of providing a solid base of data to work on for the following stages.

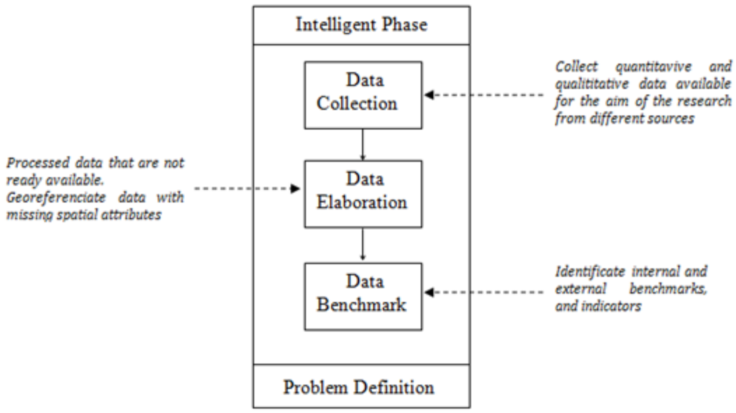

Figure 2.3: Intelligent phase

A distinction between data, index and indicators, has to be explicated and, the so-called "Information Iceberg", reported in Figure 2.4 has to be considered when assessing the information flow.

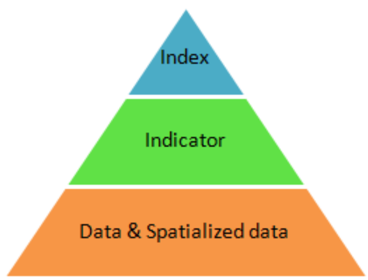

Figure 2.4: Information iceberg. Source: [84]

Data are raw numbers, (e.g. Electricity consumption for every civic number) which excludes any interpretation or any re-processing of statistical adjusting or consistency analysis. After data validation (i.e. statistical type of validation) combination of raw data allows to calculate indicators (e.g. waste production *pro capita*) whose significance permit multi-year monitoring and benchmark with similar realities.

The required passage from "data" to "indicator", used in environmental and economic fields (e.g. performance indexes such as Payback, environmental quality, ecc.) will be the main feature assessed for the study of this work.

Indicators may also be further aggregated into indexes,with the aim of unifying indicators with similar meaning, aggregating results in one or few comprehensive quantitative values.

The "Intelligent Phase" has been further subdivided into three stages, accounting for three different moments of assessment and will be discussed in the following sections:

- data collection,
- data elaboration,
- data benchmark.

2.1.1 Data collection

This stage is also called Audit and refers to the methodical examination and review of data-sets; it is the first step because before proceed into the analysis it is necessary to collect reliable data and coherent, with the aim of the work, information. Energy or Environmental Audit may be carried out in different modalities, such as Walking Through, Extensive Audit, Specific Audit, depending on the degree of specificity required by the assessment.

- Walking through-Audit, as the name suggests, are basilar inspection of the study's premises, aiming to obtain a broad analysis of the structure and the problematic affecting it,
- Extensive-Audit, on the contrary, are long term, comprehensive assessments of the structure. It requires much more effort but permit to obtain a more detailed assessment of the aim of the study,
- Specific-Audit are detailed data about the topics of the work with a precise objective, usually following to one of the previous type of assessments. Substantially data collection derives from direct access to central database of different government institution. While a central data base is usually present only in large applications or may not be consistent with current measurements. Standard indicators are useful for quick analyses of large amounts of sampled companies, when direct measurement would result time consuming when related to the project goal. In any case he choice of the strategy for data collection case-specific and case-dependent.

2.1.2 Data elaboration

As the information iceberg concerned, data identified for the study and collected in the previous step should be elaborated in order to provide relevant outcomes for the decision making process. In the SDSS, there is a crucial step, that is not present in a simple DSS that concern the spazialization of dataset. Even though some data are still spatialized, most of them are not yet, and necessitate of a right collocation in the space; as a consequence a spatialization process should be performed to that data.

2.1.3 Data benchmark

The intrinsic features of performance indicators permit a comparison among similar and real contexts. Four main categories of references exists and are

- external/internal benchmark,
- best available technologies and/or best practices,
- theoretical process values,
- regulatory limits.

This different base of confrontation has been used for comparing single indicator performances in the case study.

2.2 Design phase

The second step of a DSS and of a SDSS represents the core and creative part of the work: its main aim is providing suitable solutions for the problem to be assessed. Basically, a multi-objective model has been applied to one solution which, for many of the companies and buildings in the case study later to be assessed. This step is the main and creative part of the work; the most important because in this stage we try to find the best solution and creative because its object derive from the design of the experiment that is new and different for every DSS. The objectives of the single steps provided for the Design Phase of the methodology are deepened in figure 2.5.

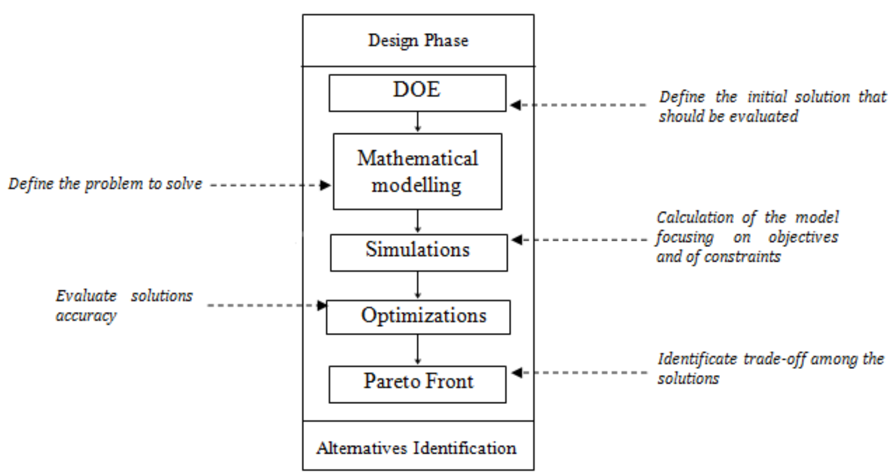

Figure 2.5: Design of Experiment

The design phase proposed in the study operates as shown in Table 2.1 and consists in the following steps:

- the simulator receive a set of initial input variable's values (in Microsoft Excel) for the optimization model,
- calculating the required output considering together variable and fixed/initial data, the simulator computes the desired output (objectives and constraints),
- depending on the optimizer, constraints are verified and feasible solutions are assessed founding on the objective functions, while solution set is eventually kept, modified or discarded. The optimizer stops after a predetermined number of iterations and non-dominated solutions are thus identified.

Stages	Aim	Tool	Software used
DOE	Define the initial state with the considered variables	DOE algorithm	Mode Frontier
Output calculation	Calculate the results from the single simulation	Mathematical model	Microsoft Excel
Scheduling	Variates the candidates solutions basing on results	Scheduling algorithm	Mode Frontier
Pareto Front	Identifies the no dominated solutions	Optimizer	Mode Frontier

Table 2.1: Stages of the DOE and relative explanation

The peculiarity of the model considered are different as explicate in the following paragraph:

- the model include a multi-objective optimization for a sustainable landscape planning considering economic, social and environmental objective function separately, avoiding processes such as externalization,
- the optimization model is run on a two-software base, using the flexibility of Microsoft Excel in data insert and calculation, while exploiting multi-objective optimization algorithms provided by the Esteco ModeFrontier© package for searching the Pareto front,
- an innovative method to weight the objective functions is here presented,
- the best solution find at the end of the process can be spatially explicated in order to better visualized the outcomes of the model.

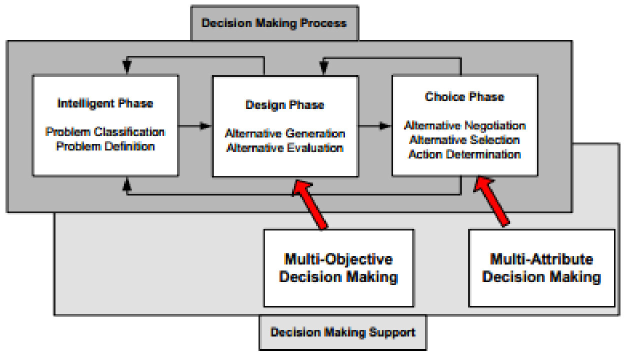

Figure 2.6: Decision making process: Multi-Criteria and Multi-Objective analysis. Adapted from [24]

2.2.1 Mathematical model

The mathematical model is characterized by a set of equations and relationships that link input to the output, and, depending on the case and of the problem, can be implemented in different software such as Microsoft Excel, OpenOffice, Matlab and others. The optimization system needs an element that, after chosen the data-set, allows to obtain the outputs that correspond to that data input. It is possible to note that this action of pure calculation is not performed by the algorithm, which as will be seen below has different purposes, but by mathematical models originated by equations.

2.2.1.1 MultiCriteria (MCDM), MultiObjective (MODM) and MultiAttribute Decision Making (MADM)

The terms multi-criteria decision making (MCDM), multi-attribute decision making (MADM), and multi-objective decision making (MODM) are often used as synonymus in DSS literature.

Multi-criteria decision making (MCDM) also called multi-criteria decision analysis (MCDA) refers to making decisions in the discrete decision spaces and focuses on how to select or to rank different alternatives [kalabande]. The term multi-attribute decision making (MADM) is also used to refer to the same set of problems indicated above, but they call "Criterion" as "Attribute". Multi-objective decision making (MODM) or multi-objective decision analysis (MODA) are two interchangeably terms usually used to indicate the same set of problems. These problems concern more than one objective, that can be maximized or minimized, "with different criteria which all may affect all objectives or few affect one and others affect both.." [Parnell]. In Figure 2.6 it is possible to highlight how MADM and MODM are located in two different moments of the analysis.

Considering the main phases of the decision making process of the Figure 2.6, it can be finally assumed that MODM provide support into the design phase, to the alternative generation allowing the decision maker to identify a range of potential alternatives. MADM instead, acts in the choice phase and supports the decision maker in the latter stage of selecting and ranking among a range of possible alternatives.

The technique called Multi Attribute Value Theory (MAVT) [52] has shown to be a very promising line of research in the field of sustainability assessments and strategic planning for territorial transformation processes due to the general opinions that attest territorial transformation processes as inherent multi-attribute problem characterized by many different and conflicting objectives.

This theory can be used to try to solve problems involving a finite and discrete set of alternatives that have to be evaluated with conflicting objectives; so it plays a crucial role in environmental decision-making where these kind of processes are often complicated by various actors and conflicting stakeholder opinions.

2.2.2 Design Of Experiment (DOE)

This stage involves the determination of what is the initial data on which to perform the simulation and optimization operations. The identification of the initial set of candidates solutions i.e. the combination of variables to be simulated by Microsoft Excel, represents a major stage in the whole optimization process. This concerns the determination of what are the samples that constitute the initial data.

This instrument enables the provision of a number of individuals data by the combination of the different variables to be used for a resolution of the first attempt of the algorithm. On the base of the results obtained, it will change this data-sets by isolating the most individuals suitable for achieving the objectives. The software used for the optimization process (Esteco Mode Frontier 7.0) allows the following DOE algorithm, whose operating principles are briefly assessed:

- user defined sequence where an initial ASCII file is directly inserted into the design space, useful when some possible solutions are already known and the optimizer can start from an already feasible solution,
- random DOE where the design space is randomly filled,
- Sobol sequence that is similar to the random DOE, but allowing a more uniform distribution of the randomly generated points of the design space,
- Constraint Satisfaction Problem (CSP), particularly used for highly constrained designs and optimization algorithms requiring an initial feasible solution to operate,
- Latin Hypercube, which is another random DOE that divide the distribution over homogeneous intervals to improve the spread of the possible candidates,

- full Factorial DOE, where after having defined the variable levels (the number of possible values) for each variable, the total number of combination is calculated. Useful for problems with low number of variables, because of the large computing required for assessing the whole design space,
- reduced Factorial DOE is similar to the previous methodology, but with a maximum of 2 levels for each variable,
- Cubic Face Centered DOE, which is a 2-level full factorial DOE , but also considering mid points each variable combination of the design space,
- Box-Behnken DOE, which considers the center of the hypercube constituted by the design space, plus the midpoints of each variable.

The software also allows other DOE algorithms but the choice among the different types of DOE will be assessed in the specific application of the process.

2.2.3 The optimization algorithm

After having fixed the initial set of solution for which the output values have been assessed, the optimizer has to decide how to move from a set of candidates to the next one, in order to identify best-performing solutions. In other words, the optimization algorithm has the aim to select the population produced on the basis of the generated problem solutions, classify them according to a hierarchy of affinities with the objectives of the problem and finally determine which can be reproduced. This process, also known as scheduling, depends on variables such as:

- continuous vs. discrete variables;
- search operators: mutation/selection/crossover;
- relation among generations;
- varying the number contemporary assessed variables.

2.2.3.1 Pareto front

The next stage is the awarding of the degree of suitability (fitness assignment): the most used methodology for that step is based on the optimization according to Pareto. It asserts that you can define a front of solutions that can be achieved through the ”trade-off” (i.e. the balance between two equally desirable options but conflicting) among the objectives.

The concept of Pareto optimal condition is closely linked to the domino concept defined as follows: “Considering, without loss of generality, to minimize the n components fk, k = 1, ..., n, of a vector function f, where f (x) = {f1 (x), ..., fn (x)} is a vector of objective functions, n is the number of considered goals or criteria, x = {x1, ..., xp} is a vector of variables in the universe U and p is the number of variables that include the complete solution".

In absence of additional information, the multi-purpose solutions to the problem are compared using the concept of Pareto Domain.

The set of all vectors that respect the rule of Domain according to Pareto, are defined feasible solutions of the problem, or even, Pareto Front. Fonseca and Fleming [1993] proposed another different approach from the classical one; where the the rank of an individual corresponds to the number that dominates it. In this way, all those not dominated solutions are characterized by the same rank, while the others are penalized based on the density of this population in the corresponding trade-off of the surface region; the algorithm iterates through this process until all individuals are not cataloged. This algorithm, defined by Fonseca and Fleming [1993] is called MOGA II (Multi Objective Genetic Algorithm). It is used in this study with 100 repeats.

The MOGA II, starts from a set of candidates solutions (called also "parents") and evolves in more candidates (the "children"), by using the following search operators:

- crossover: recombination of parents,
- selection: maintain designs,
- mutation: changing only limited designs.

The methodology allows elitism (best solution of each objective are preserved from one generation to the next one) and treats constraints in order to ensure best constraints satisfaction among generations. This can be done by adding an objective equal to the number of violated constraints to be minimized.

2.3 The choice phase

A set of compromising solutions to the problem it is now identified and the choice among them represents the last step of the decision making process.

Choosing among different variables has to be necessarily related to the specific case study assessed and provide a general scheme for all the problems would be an error. However, several methodologies have been developed for assisting qualitative and quantitative decision making process. Figure 2.7 illustrates the main steps before achieving the choices.

2.3.1 Scenario analysis

Scenario analysis is a methodology typically used to model real problems where decisions are based on uncertain future; this uncertain can be described with the formulation of future results defined as scenario. Since making a sustainable decision is to be able to determine what is best to do now in relation to the future development, it is essential to assist the decision makers not only with a method that allows them to compare an alternative to another and each other,

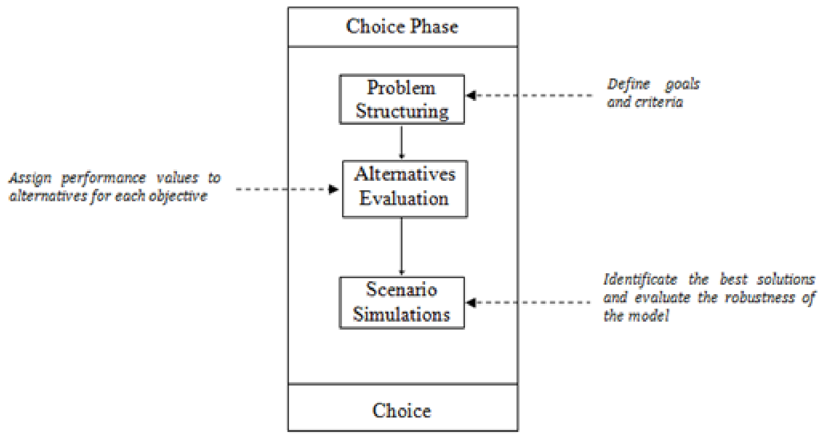

Figure 2.7: Choice phase

but also with a methodology that give the opportunity to develop such scenarios in a consistent and robust way, without unreasonably increasing the number of scenarios to be used.

Predict the future is mainly to answer three questions [47]:

- possible Future: "What could happen?"
- probable futures: "What is most likely to happen?"
- preferable Future: "What you would prefer to happen?"

There are many methods to do this:

- the quantitative analysis of the trends: it consider the future as a continuous development of the past. From the data of the past it is possible to predict the development of a phenomenon; they ordinarily employ a time horizon of 1 to 5 years,
- the simulation method: it used the mathematical relationships to provide a system which permit to observe the behavior in the future. They are typically used to analyze a medium-short horizon, in which there are some certain parameters,
- the Delphi method is finally the best known and used today. It is based on a process of consultation of a panel of experts with the use of questionnaires about the performance of some future variables,
- the scenario analysis method is one of the most interesting models. Indeed, it allows to reach the most distant time horizons (10 years and over) and

has proven over the years to be a well-structured method to create "what if" investigations and explore the uncertainty consequences.

Scenario can be defined as the description of a possible set of events that can reasonably happen. The main purpose of the development of a scenario is possible to think about the events, laws that put them in relation with each other, the possible opportunities and risks and action policies.

There are several useful tools to develop the scenarios: on the one hand, they can be born by a single individual or from a group as exercise of imagination (therefore with a high degree of subjectivity), may include back-casting (starting from a state predetermined future and try to bridge the sequence from that future may bring to mind) rather than forecasting, quantitative or the qualitative description, the average trend or exceptional events. From a mathematical point of view the scenario analysis can in fact be classified into three different types:

- Holistic Scenario Analysis: develops scenarios by a panel of experts; despite substantially on qualitative analyzes developments, it is also possible to include more quantitative aspects, combining in each case is the intuitive ability of experts and formal analysis,
- on the model Scenario Analysis: uses a model in which they may influence the independent variables, and they create a series of trajectories of other parameters that allow you to draw a set of possible futures,
- Formative scenario Analysis (FSA): it is based on a series of factors chosen qualitatively and on a set of relationships between them weighed by a group of experts. With a high number of impact factors of course the number of possible scenarios can be very high, so it is essential to introduce some indicators that allow you to reduce these possible scenarios and to obtain a subset.

The objective of FSA is to obtain a final set of scenarios to be analyzed that has characteristics of:

- consistency: the scenarios that contain contradictions or unrealistic situations must be erased,
- difference: scenarios with little mutual difference, even if some, do not offer information from the subsequent analysis point of view,
- numerically content,
- reliability: the selected scenarios must have passed an objective and repeatable procedure,
- efficiency: few highly representative scenarios.

2.4 Representative phase

This is a new phase specially designed for the Spatial Decision Support System not yet implemented on Mode Frontier and in this study (Figure 2.8).

During these phase the spatial contribution permits to visualize again in a map the final configuration and asset of the study area.

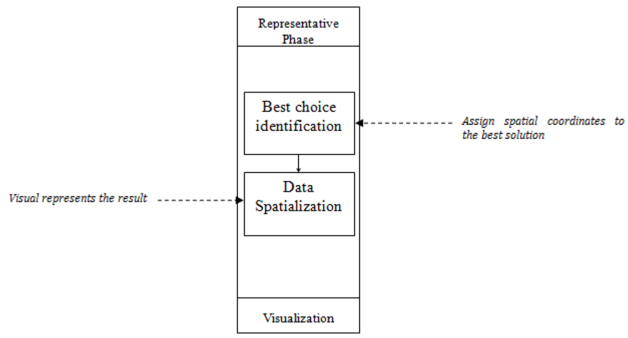

Figure 2.8: Representative phase

2.4.0.1 Weight of the alternatives

Having the results of the model, in order to visualize different scenarios for decision makers and to help them to take sustainable decisions, an new method for weighting the objective functions is here proposed.

The innovative method to weight the objective functions needs to define how, the single category of objective function, takes to reach the target for social, economic and environmental categories given by the European Union for the year 2020.

This is explained in Equation 2.1:

$$F = \alpha En + \beta Ec + \gamma S \tag{2.1}$$

The score F of the single scenario is given by the sum of the three values of the objective functions that are weight with a coefficient equal to the gap between the current situation and the achievement of the European Union for the year 2020 for social economic and environmental component. In the Equation 2.1 they are represented with α for the energetic and environmental (En) category, β is the economic (Ec) one and γ is that for the social (S) one.

In this way, every single scenario can be evaluated as function of European politics, it is objective and in case of variation of European Union targets (es. target 2050) allows an easy evaluation.

Chapter 3

Case study - Data for Investigative phase

At present, UM studies focus on the biophysical environment without addressing the social and institutional drivers behind these flows and outcomes. Data gaps, omitted flows, uncertainty regarding the appropriate scale of analysis and segregated information sources continue to influence the comprehensive validity of assessments of overall urban energy use and related policy decisions. Collaboration and open communication across sectors and research centers working on sustainable energy problems is also critical for developing a comprehensive pool of information that is accessible to various users and end types. Previous studies [83, 62] suggest that selected evaluation tools are classified according to one the following tool types:

- design guides – descriptive collections of sustainable urban development themes. They present checklists as practical instruments to guide the design process,
- calculation tools – software tools for direct calculation of sustainable urban development indicators, facilitate aggregation of indicators for visualization of thematic maps of individual indicators,
- assessment tools – advanced checklists with software implementation. They are important for a sustainable urban development theme of structural evaluation framework, results were plotted in charts providing a visual and quantitative profile of different design options,
- rating systems – similar to assessment tools; they require precise calculation of indicators and include target values and weights for aggregating results into the final score.

Finally, it is important to have the possibilities for customizing the tool for the specific context of the project, by configuring or selecting the indicators in a specific way ([17, 125])

Gil and Duarte [62] proposed also a general structure for sustainable urban development evaluation tools consisting of the following five hierarchical levels with increasing detail and specificity:

- sustainability dimensions – the core goals of sustainability, often based on the three pillars of environment, society and economy,
- urban sustainability issues – themes of concern to sustainable urban development, which need to be studied to achieve the objectives (e.g. resources, accessibility, viability),
- evaluation criteria – the aspects that need to be assessed in order to verify the response of the plan to the issue (e.g. energy consumption, waste production, access to public transport or access to jobs),
- design indicators – measurements that are indicative of the performance of the design, with specific measurements and methods,
- benchmark values – reference or target values that the indicators need to meet to achieve specific quality levels.

The main benefits of DSS include: improved data structuring and management, creation of new evidence to support decision making, exploration of personal knowledge and preferences, promotion of learning, and more informed problem solving.

For a sustainable landscape planning, with the aim of reducing GHG emissions, the Spatial Decision Support System has been designed with a holistic model that can describe the environmental condition of energy (electrical and thermal) and water consumption at building level, the amount of traffic in a territorial context and the situation of green areas. Thus, allowing a comparison between different sustainable alternatives, e.g. systems that use different combinations of technologies, which is useful in assisting the decision-maker in making the best choice.

The ultimate goal is to create a tool that allows to put the various actors in various roles in decision-making conditions to better understand how their actions can affect the sustainable planning of the considered territory as the Convent of Majors asked to perform.

The elaborations proposed will investigate the results of the actions proposed in the PAES [PAES] in terms of emission reduction.

The research focuses on developing a Spatial Decision Support System (SDSS) that uses multifunction and optimization models to address environmental planning problems and specifically to calculate CO_{2eq} emissions in the territory.

The study will focus on the municipality of Tavagnacco due to the availability of detailed data with a very high accuracy. Furthermore, in this municipality PAES [PAES] is available and the culture of smart city is widespread.

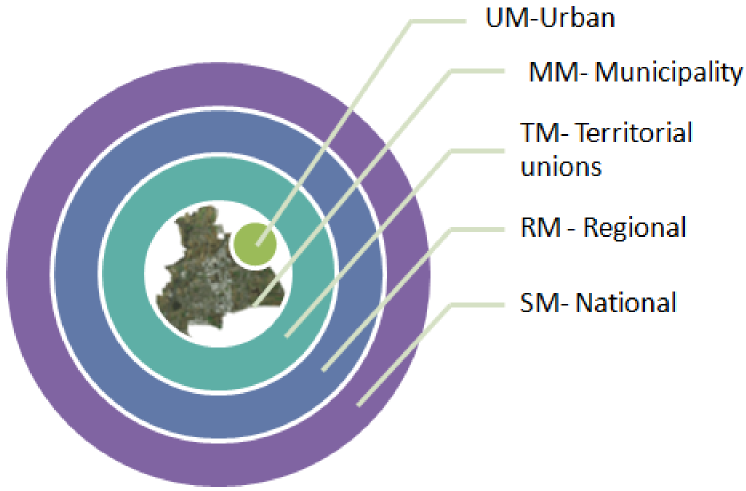

Figure 3.1: The metabolism used

3.1 Study area

Urban Metabolism can act at various level (Figure 3.1), in this study a Municipality Metabolism was developed.

The municipality of Tavagnacco is located approximately 137 meters above sea level, at the borders of the Udine municipality. It is located between the streams Cormôr and Torre and extends up to the first recesses moraine, with a total area of approximately 15.25 square kilometers.

The territory is surrounded on the north by the municipalities and Tricesimo Reana del Rojale, to northwest from that of Pagnacco that, with troughs of Cormôr, delimits the border, west from those of Martignacco and Pasian di Prato and, finally, to the south and east, from Udine. The municipality includes, in addition to Tavagnacco, the villages of Adegliacco, Branco, Cavalicco, Colugna, Feletto Umberto.Approximately 43% of the population is concentrated in the village of Feletto Umberto and 17% resides in Colugna.

Tavagnacco was one of the first municipalities in the Friuli Venezia Giulia region to express interest in the low carbon initiatives, and in this way made official on December 29, 2010 by the City Council, who have voluntarily adopted the "Covenant of Mayors". As already introduced, in the PAES [PAES] for the municipality of Tavagnacco the main actions to consider are:

- reductioning of energy consumption of municipal property assets (buildings and public lighting system),
- upgrading the energy efficiency of the residential building and commercial assets,

- promotioning of sustainable mobility in urban areas,
- increasing of local production of energy from renewable sources,
- spreading of a culture of saving and energy efficiency among citizens and operators of the territory.

The Covent of Mayors established a plan in order to meet required targets.

The document identifies the areas of most appropriate intervention and the most appropriate opportunity to achieve the reduction target of CO_2. It defines concrete reduction measures, together with timing and responsibilities, and thus turning the long-term strategy into an action plan. The Covenant of Mayors focuses on local measures within the local authority's power. The PAES [PAES] should concentrate on measures to reduce CO_2 emissions and the final energy consumption by end users: the actions of the PAES [PAES], must cover both the public and the private sector.

However, the local authorities should lead by example, adopting the leading measures for their buildings, systems, the vehicle fleet, etc. The PAES [PAES] also includes interventions related to local electricity production (photovoltaic energy, wind energy, CHP, improvement of local power generation) and the local heating / cooling generation. In the field of renewable energy, the municipality of Tavagnacco has already installed and started the production of renewable energy at a number of municipal building, the status at 2012 was the following:

- photovoltaic system on the roof of maternal school of Adegliacco. kW power 17,49. Active since 11/10/2004,
- photovoltaic system on the roof of the elementary school Feletto. kW Power 19.95. Active since 02/11/2005,
- photovoltaic system on the roof of the middle schools in Feletto. kW power 17,70. Active since 20/01/2006,
- geothermal power plant at the nursery school Adegliacco. kW Power 74 . Active from 07/07/2011,
- photovoltaic system on the Municipal Auditorium coverage. kW Power 19.8. Active since 17/02/2011. With this plant, the Municipality has given the right to use the area to a private company that installed the system,
- on the Mill of Adegliacco: Installation of about 11 kW currently emitted on network. Active since 29/02/2012. This plant is for the production of electrical energy via the water-powered mill wheel,
- photovoltaic system installed at the municipal office, which is in the course of implementing the new Council Chamber. Currently this plant generates approximately 11 kW of energy. This could be extended to 18 kW if it is expanded.

3.2 SDSS Data

The carbon flows can be divided into three categories:

- Carbon extractions which are mainly in terms of building materials, goods, fuels and electricity supplied from the urban system to the communities.
- Carbon exchanges among different functional sectors in urban communities which include supply, transportation, consumption and pre-treatment of carbon-embodied materials and energy, as well as the absorption of released carbon dioxide by landscaping.
- Carbon emissions which include both direct release and indirect emission embodied into the waste discharged to the urban environment.

Lu et al. [2015] attested that there are seven metabolic sectors to take into account when calculating the carbon cycle inside a municipality:

1. urban environment supplying resources and treating wastes,
2. energy sector allocating fuels and power to the community,
3. construction sector providing physical settlements,
4. household sector consumption of municipal residents,
5. service sector providing public services,
6. waste sector collecting and pre-treating solid waste and sewage, and
7. landscaping sector.

Urban metabolism has been studied for only a few cities worldwide due to difficulties obtaining adequate statistical data [114]. Considering the main objective of the study, data collection has been done with the aim of identifying both the absorption, and the emission factors for CO_2 balance.

In the case of Tavagnacco all the seven metabolic sectors listed above are taken into account with the exception of the construction sectors one due to the availability of data. Data collected cover more years, in few cases from 2004 to 2014, but it was decided to use the year 2012 as reference due to the large availability of data for this year; unfortunately not all the data belonged to the baseline data but they were considered temporally the closest as reported in Table 3.1.

3.2.1 Data collection

To evaluate the absorption of CO_2 in the municipality of Tavagnacco data used was a set of very high resolution (9 cm) aerial images of the municipality dated December 2011.

While to calculate the emission of CO_{2eq} in the municipality the allowing additional data were acquired:

	Years	Year chosen
High resolution Images	July 2008 and December 2011	2011
Energy consumption	From 2003 to 2014	2012
Electricity consumption	From 2003 to 2014	2012
Waste production	2012-2013	2012
Particular waste disposal	From 2012 to 2014	2012
Water consumption	From 2012 to 2014	2012
Traffic simulation	2012	2012
Traffic evaluation (buses)	2016	2016
Traffic evaluation (trains)	2015	2015
Traffic evaluation (highway)	From 2008 to 2013	2012
Fleet vehicles	2015	2015

Table 3.1: Availability of data per year

	Energy consumption	Electricity consumption	Water consumption	Waste production	Traffic simulation
Residential areas	✓	✓	✓	✓	
Industrial areas	✓	✓	✓	✓	
Agricultural areas	✓	✓	✓		
Traffic					✓

Table 3.2: Data used for sector evaluation

- energy consumption,
- electricity consumption,
- water consumption,
- waste production,
- traffic simulation.

In order to highlight the flexibility of the model, Table 3.2 illustrates the datasets used to evaluate CO_2 emissions for every sector.

3.2.2 Data Elaboration

Processing of collected data consist mainly in the geolocalization of the addresses contained on tables achieved from the municipality. Particular processes were performed on the production of the landuse map and they are well explained in paragraph 3.2.2.6.

Data collected	Availability as a map	Data elaborated
Energetic (methane) consumption	After geolocalization	Energetic (methane) consumption map
Electricity consumption	After geolocalization	Electricity consumption map
Water consumption	After geolocalization	Water consumption map
Waste production	After geolocalization	Waste production map
Simulation of traffic	Yes	Traffic map
Local strategic plan	After data statistics	Traffic map
Aerial images	After processing	Land use map
Lidar Data		Vegetation map
Particularly waste disposal	After geolocalization	Industrial areas map/ company geolocalization

Table 3.3: Elaboration carried out on the data-sets

After georeferentiation all the data were immediately used (Table 3.3) in the production of maps. This was a major and time consuming step in the overall process.

3.2.2.1 Energetic and electricity consumption

All the municipality of Italy can acquire data on energy consumption, from the authority ”Agenzia delle Entrate” which allows the opportunity to know the quantity and the costs of electrical energy and methane that every citizen has used.

These data-sets in the original form can be acquired in Excel format and are composed of data such as year, fiscal code, vital statistics data, address, civic number and costs. Data are available from 2003 to 2014 and it was decided to use the year 2012 as the baseline. In order to georeference these datasets a script on Microsoft Access was produced: the script works looking for the correspondence on fiscal code on the data-sets of consumption and residents from the data-sets of taxpayers. Then in order to localize the residual amount of data not georeferenced, the Access script looks for the correspondence of addresses (street and civic number with both number and letters). Problems in the automatic process concern:

- addresses without civic number,
- non-existing addresses,
- addresses from other cities,
- format of the addresses (i.e. scale and internal addresses) and writing mode (i.e. 4 November vs IV November),

- energy consumption of the buildings of the municipality that are without addresses,
- buildings that are under construction, and do not have an address or a taxpayer to refer to, and the consumption of these buildings are addressed to the company in charge of work.

When the process is finished few addresses are not georeferenced and to complete the dataset, the work should be done by hand, line by line. After this process it is possible to have a map of consumption for all people but, in order to associate it to the civic number, the consumption must be summed up for every building.

Values from the dataset of electric energy are given on kW and in order to obtain kWh, an hypothesis of used of electric energy was formulated, results are reported on Table 3.4.

	kW	h	kWh
Civil	3.873.450	4	15.493.800
Industrial	3.405.149	8	27.241.192
Commercial center	888.210	20	17.764.200
Total	8.166.809	-	45.005.392

Table 3.4: kWh consumption of electric energy

After that process, it was possible to obtain the map of methane consumption (in Figure 4.15) and the map of electricity consumption, (Figure 4.16). Figure 3.2 reported instead, the heatmap of energy and electricity consumption and it is evident that the major consumption of energy is from industrial areas where there are no residents.

In order to visualize the total amount of energy consumption it is possible to convert the energetic and electricity consumption into the tons of oil equivalent (toe) with the coefficient 8.22*10ˆ-4 for m^3 of heat energy and 1.87*10ˆ-4 for kWh of electric energy and sum up the results: the outcome is a map (Figure 4.17) of total toe in the municipality derived from energy consumption. Again the Figure 3.3 demonstrates that the major consumption comes from industrial and commercial areas where there are no residents.

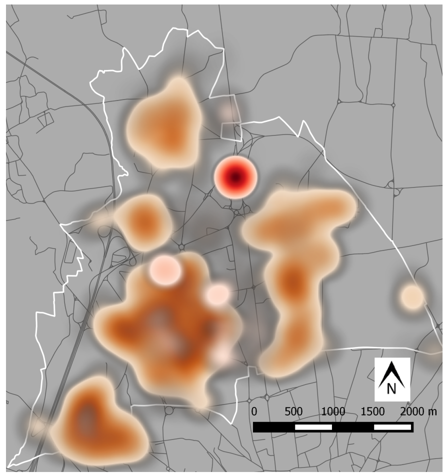

Figure 3.3: Heatmap of Toe over residents one

3.2.2.2 Traffic data

The most reliable traffic data currently available for the Friuli Venezia Giulia region comes from the following various sources:

- the Regional Road Safety Plan, which contains in the last pages the traffic data of the year 2005, obtained from measurements and calculations with specific software,
- the traffic data collected continuously (24h per day) from 2010, to 12 portals installed along various regional and state roads placed in the district Udine - Gorizia - Monfalcone - Cervignano: these data are too far and out of the study area,
- a traffic simulation of the main streets of Tavagnacco municipality of 2012,
- the regional action plan that derives from art.8 of the regional law 16/2007 where there is a daily and weekly analysis of the contribution of the pressures of traffic.

Unfortunately it was not possible to use the first data-set because data were too out of date and there is a stark difference from the reference year considered for this case study but these data will be used at the end to compare results of the traffic simulation.

The Friuli Venezia Giulia region provide a traffic simulation for the study area based on data manually acquired then processed with the software Visum©. Data was acquired in 2012 from 7.30 to 8.30 during a weekday, for light and heavy vehicles.

The region FVG in the simulation of traffic with Visum discern only from Light (urban passenger vehicles) and Heavy vehicles (commercial vehicles).

Statistics from the regional action plan were used to elaborate daily and weekly traffic of passenger and commercial vehicles.

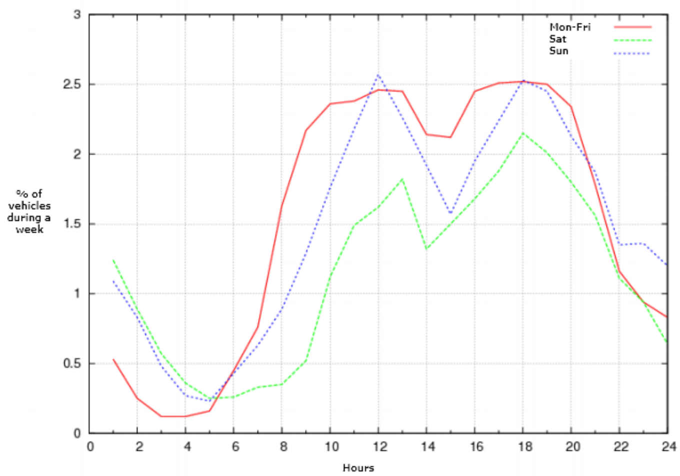

Figure 3.4: Daily and weekly trend of urban passenger car traffic. Source: [FVG]

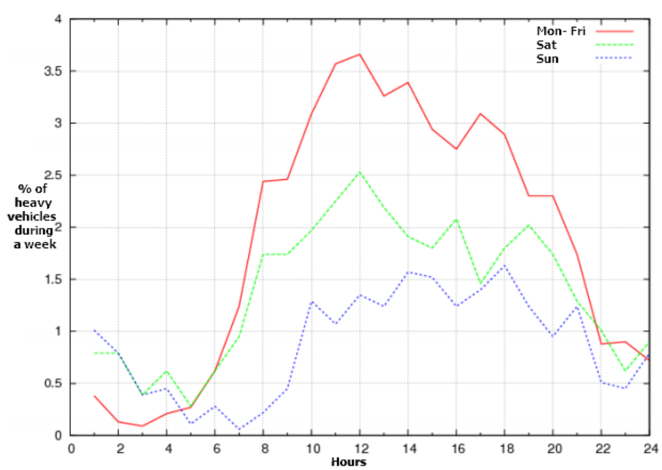

Figure 3.5: Daily and weekly trend of commercial vehicles traffic. Source: [FVG]

Available data consider heavy and light traffic only per one hour that was considered as a mean value into the 24 hours for light vehicles, and as one of the most high traffic hour for commercial vehicles, as reported n Figures 3.4 and 3.5.

As shown in Table 3.5, assuming equal to 100% the total number of cars crossing a city in any of the weekdays, the Sundays show a decrease of about 10% if compared to midweek traffic, and only 2-3% on the Saturdays. More differences are observed in the traffic of commercial vehicles that decreases by more than 10% passing from weekdays to Saturday and Sunday. The daytime trends in the use of cars shows a clear shift of traffic for the morning toward the middle of the day passing from any of the weekdays, to Saturday and Sunday. Both, on Saturday and Sunday it is evident that there is a greater presence of traffic in early hours of the morning, which probably linked to the attendance of nightclubs.

% of Vehicles	Monday-Friday	Saturday	Sunday
Passenger vehicles	100	96	74
Commercial vehicles	100	74	39.75

Table 3.5: Daily percentage of vehicles that transit in urban centers. 100% corresponds the average of the vehicles on the days from Monday to Friday. (Source: FVG Region, 2007)

Weekly data collected for commercial and urban passenger traffic was transformed into the annual amount of traffic, assuming that during a year there are 52 weeks.

Finally data simulated were compared with respect to the Regional Road Safety Plan and results were similar.

A separate evaluation should be done for the highway that is present in the municipality. In 2012 the average number of light vehicles on the highway was 10.249 in the direction north-south and 10.476 in the direction south-north; for the heavy vehicles there was 3.200 in the direction north-south and 3.263 in the direction south-north, with a total amount of vehicles per day of 30.180.

These numbers have considerably decreased with respect to the year 2011 as reported in Table 3.6, and this confirms the high variability of this particular kind of data.

	Heavy vehicles			Light vehichles			Total		
	2011	2012	% Var	2011	2012	% Var	2011	2012	% Var
Udine - Tarvisio	3.635	3.263	-10,2	11.638	10.476	-10	15.274	13.379	-10
Tarvisio - Udine	3.554	3.200	-10	11.353	10.249	-9,7	14.907	13.448	-9,8

Table 3.6: Average daily transits on the highways

The concentration maps summarize and display the evaluation of traffic for the main roads of the municipality: while the heavy traffic is concentrated on the nearest of the highway, the light traffic is sprawled over the whole area.

Final maps are proposed for all type of vehicles in Figure 4.21 and in detail, for light vehicles is shown in Figure 4.19 and for heavy vehicles is proposed on Figure 4.20.

3.2.2.3 Industrial buildings map

The authority ”Camera di Commercio” doesn't provide a data-sets on the industrial and commercial companies that are presented on the study area.

In order to obtain a map of the localization of those companies, the data-set of particular waste disposal was analysed.

NET spa has provided a list of the industrial and commercial buildings due to the fact that these companies should treat their waste separately from the urban ones.

The data-set also contains a reference number of the main activity connected with the company and linking this information with the list of the general types of activities it was possible to discern manufacturing activities from health activities and so on.

Then the last step before achieving a map of the industrial activities was to georeferenciate the companies with the maps of civic numbers.

The result obtained is presented in Figure 4.14. In the heatmap reported below it is clear that there is a clear discrimination between the industrial and commercial areas, and the civil ones as there is a very little overlap are visible in Figure 3.7.

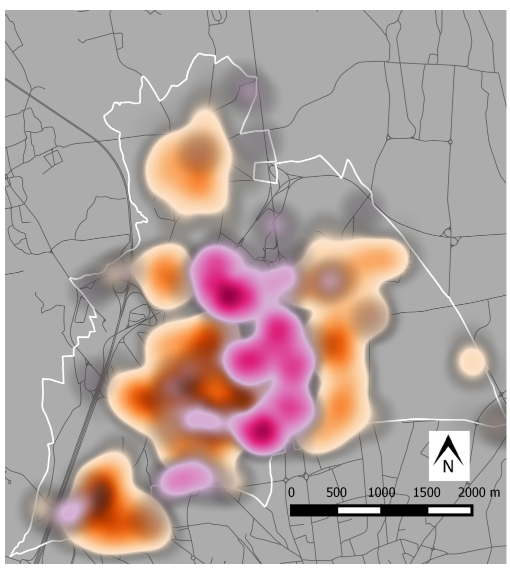

Figure 3.7: Heatmap of civil and industrial areas

3.2.2.4 Waste production map

NET spa, the company that manages the separate collection and treatment of waste in Tavagnacco has provided the data relative to the waste production of different materials as kg for every inhabitant and as total kg for the municipality and a different database for industrial and commercial companies.

The considered waste are reported in Table 3.7, with a reference to the total amount of waste product per inhabitant.

Waste and CER code	Kg	Recycle %
Inorganic waste (200301)	112,18	41.7
Organic waste (200108)	73,01	95
Durable goods (200307)	5,71	14
Waste from road sweeping (200303)	5,20	43
Paper (200101)	42,12	70
Cardboard (150101)	22,94	70
Glass (150107)	33,49	100
Pneumatics (160103)	0,23	55
Battery (200133)	0,16	43
Medicine (200132)	0,22	43
Plastic (150102)	29,30	85
Ferrous (200140)	4,04	88
Construction and demolition waste (170904)	13,04	43
Grass (200201)	47,04	95
Exaust oils (200126)	0,05	55
Vegetal and animal oiIs (200125)	0,14	55
Toner (160216)	0,01	43
Wood (150103)	8,56	100
TV/PC (200135-200136)	2,50	14
Fridge (200123)	0,81	14
Solvent (200127-200113)	0,23	43
Fluorescent tube (200121)	0,04	43
Spray cans (150111)	0,02	43
TOTAL	401,02	-

Table 3.7: Waste production and percentage of recycle per residence per typology

No specific spatial data are available for this topic but inside the municipality of Tavagnacco there is a spatial localization of the resident for every civic number. In this case, the calculation considers the association between the number of inhabitant per civic number and the total amount of waste produced.

The main problem of this map concerns the industrial and commercial buildings that have a special waste collection.

Every line of this database considers a different industrial waste and in order to evaluate the total amount of them for every industrial and commercial activity the columns relative to "production of waste" was summarized referring to the column "company name". In any case it is evident from Figure 3.8 that the major production of waste originates from an industrial area in the middle of the municipality.

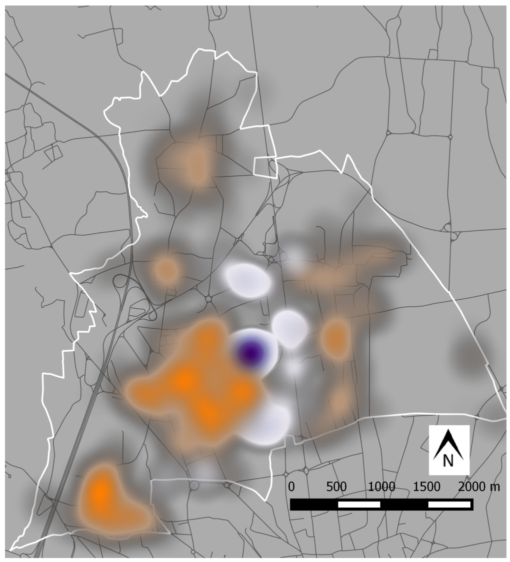

Figure 3.8: Waste heatmap

A second map (Figure 4.22) was then generated; not all the waste produced will be sent to landfills. A map was produced showing the impacting waste, and from this map it can be seen that only a few portion of waste is impacting and that the most impacting waste is the civil part as highlighted in Figure 3.9.

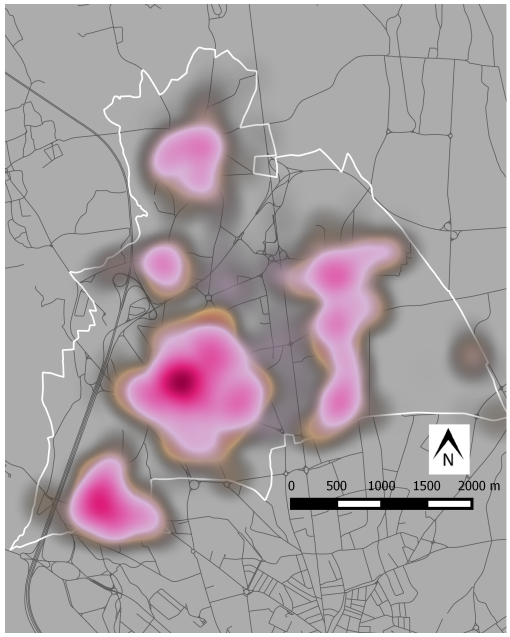

Figure 3.9: Impact waste heatmap

3.2.2.5 Water consumption map

The data-set concerning water consumption is useful to evaluate the total carbon emitted for water supply activities per year.

CAFC spa has provided the data-set as an Excel file containing the total consumption and the total costs for every inhabitant and the main elaboration has been again the geolocalization of the consumption; result is visible in Figure 4.23. The heatmap in Figure 3.10 shows the clear overlapping between inhabitants and water consumption with a spots of consumption in the area where there is the commercial center.

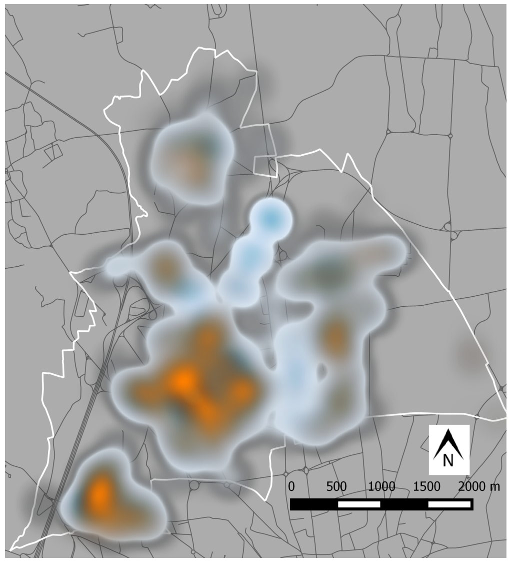

Figure 3.10: Heatmap of water consumption

3.2.2.6 Landuse map

The terrestrial biosphere can act either as a source or as a sink for atmospheric CO_2, and has been considered to hold the key to the 2 Gt C year−1 discrepancy that persists in estimates of the global carbon cycle designated by the Intergovernmental Panel on Climate Change as 'residual terrestrial uptake' [IPCC]. Both the vegetation and the soil may play a part in the residual terrestrial uptake. Therefore, a new challenge in the context of climate change mitigation is the management of terrestrial ecosystem to conserve existing carbon stocks and to remove carbon from the atmosphere by adding to stocks [Mahali]. Every class of land use of the territory, from human activity to natural ecosystems, change each soil carbon-carrying capacity: the equilibrium carbon stock is the result of a balance between inflows and outflows to the pool [50, Guo].

Nowadays, high resolution aerial images are widely available thanks to the diffusion of advanced technologies such as UAVs (Unmanned Aerial Vehicles) and new satellite missions. Although these developments offer new opportunities for accurate land use analysis and change detection, cloud and terrain shadows actually limit benefits and possibilities of modern sensors.

High resolution aerial images support a wide range of application fields as biomass estimation for energy studies, water analysis for pollution detection, environment and ecology investigations, and urban sprawl assessment. In particular, for the evaluation of climate changes it is important to identify the land use associated with carbon sequestration, specifically vegetation and soil [126, 94, 95, 108]. Even if the agriculture and forestry roles, among the global warming mitigation strategies, are not well defined, recent studies have highlighted that forests and agriculture have a high absorption capacity of greenhouse gases [26, 59], and that some agricultural management practices will lead to a carbon sequestration also in the soil [95, 137]; other researchers have demonstrated that the agricultural sector accounts for over 30% of greenhouse gas emissions [56]. In terrestrial ecosystems the amount of carbon in soil is usually greater than the amount in living vegetation. It is therefore important to understand the dynamics of soil carbon as well as its role in terrestrial ecosystem carbon balance and the global carbon cycle. The loss of soil organic carbon by conversion of natural vegetation to cultivated use is well known: Changes of land-uses result in rapid declines in soil organic matter [126].

Remote sensing literature presents several approaches to achieve an accurate unsupervised classification for detecting land use classes relevant for CO_2 absorption: among these, Maximum Likelihood [69], K-Means [141], and Self-Organizing Map [154] are techniques currently applied and available in many free and proprietary software. Although VHR images are capable of providing high precision measurements for classification procedures, they frequently contain cloud and cast shadows that generate problems for the reliable extraction of the needed information [53, 104]. Commonly, shadows cause partial or even total loss of radiometric signature in the investigated area and therefore the process of classification and object detection can be biased or even fail [3, 20, 45]. From the previous considerations, to properly classify images it is mandatory to reduce or remove shadows, and this requires their accurate identification [46, 96]. The problem of shadow detection and removal on VHR aerial color images was deal new solutions were proposed aiming at enhancing common unsupervised classification procedures for the detection of land use classes associated with the CO_2 absorption.

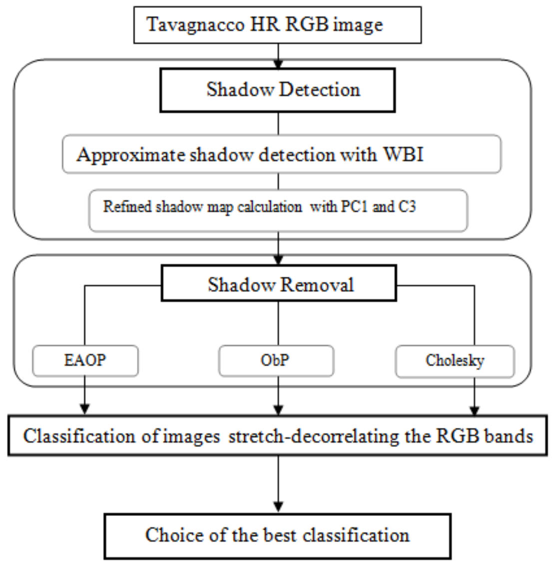

Figure 3.11: Methodology workflow for landuse classification

The methodology applied is presented in Figure 3.11 follow three main steps: shadow detection, shadow restoration and classification of new images with the final choice of the best classification based on previous studies.

Shadow Detection

To find the correct methodology for having a good landuse map a test image of the municipality of Tavagnacco, has been chosen for completeness, complexity, and for significant presence of land uses associated to CO_2 absorption. The image is dated December 2011 and has a size of about 26 million pixels with 9 cm ground resolution.

The scene is characterized by large green areas and there are different types of shadows covering more than one third of the surface. With the aim of identifying the interested land use classes, an initial unsupervised classification of the original image has been performed employing K-Means (KM), Maximum Likelihood (ML), and Self Organizing Maps (SOM). Results are reported in Figure 3.12

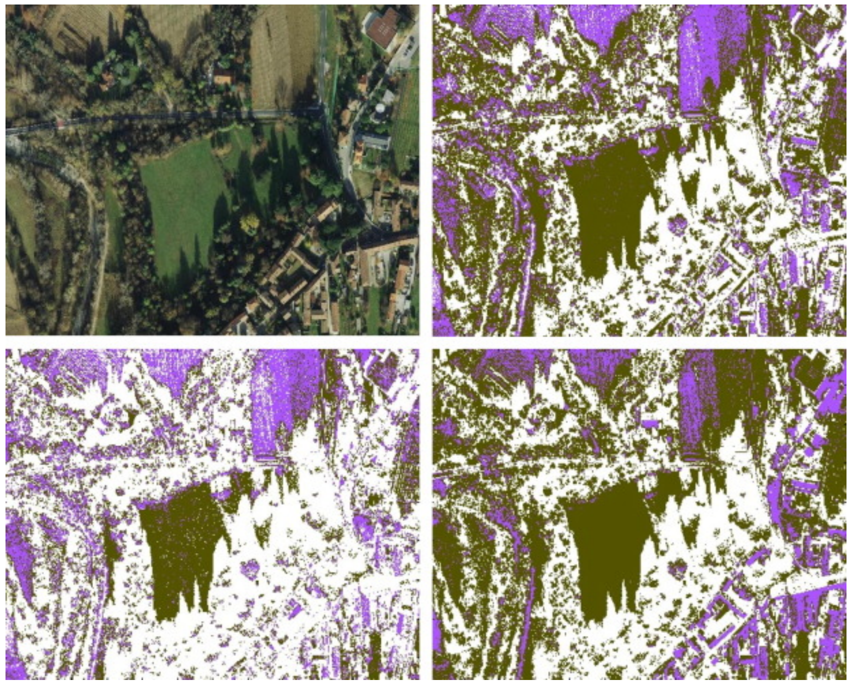

Figure 3.12: Unsupervised classification of the original image

Invariably, these methods have produced a large amount of misclassified pixels due to the presence of shadows that strongly influences the automatic cluster assignment, resulting mainly in a separation between shadow and non shadow areas: as consequence, tree shadows have been generally classified as urban areas, particularly by ML, or associated to vegetation and urban areas by KM and SOM. Shadow reduction has been therefore considered an essential step to achieve a reliable classification.

Existing algorithms for shadow detection require user interaction and manual setting of proper parameters; with the goal of processing many large data-sets, priority was given to experiment with full automatic techniques for unsupervised extraction of shadows in the scene. Shadow detection can be directly performed by computing specific parameters in the RGB space; the indexes considered were those developed by Tsai [2006], the Normalized Saturation-Value Difference Index (NSDVI) proposed by Ma et al. [102], and the Water Body Index (WBI) of [45]. For each calculated index the Otsu's method was applied to estimate an optimal threshold to distinguish shadow pixels from no shadow ones in order to obtain a Boolean map of the shadow regions.

The comparison of the various solutions with a shadow map manually produced showed that applying WBI and NSDVI represented the most effective methods as reported in [109, 110]; since overall accuracies were still unsatisfactory, more efficient shadow detection solutions were investigated focusing only on approaches operating in the RGB space, without the fundamental support given by the infrared band.

The proposed procedure is based on the following steps: WBI, PC1, and C3 (common remote sensing indexes) are initially computed for the entire image; Otsu's threshold method is applied on WBI to select a wide and significant temporary set of shadow pixels; Mean and standard deviation of PC1 and C3 are computed solely for the pixels previously identified by WBI as shadow; Shadows are detected over again for the whole image finding those pixels that simultaneously fulfill the following conditions, reported in Equation 3.1 [110]:

$$PC1 < [mean(PC1)_{WBI} + std(PC1_{WBI})] \ and \ C3 > [mean(C3)_{WBI} - std(C3)_{WBI}] \tag{3.1}$$

The improvement of this new index is demonstrated visually in Figure 3.13.

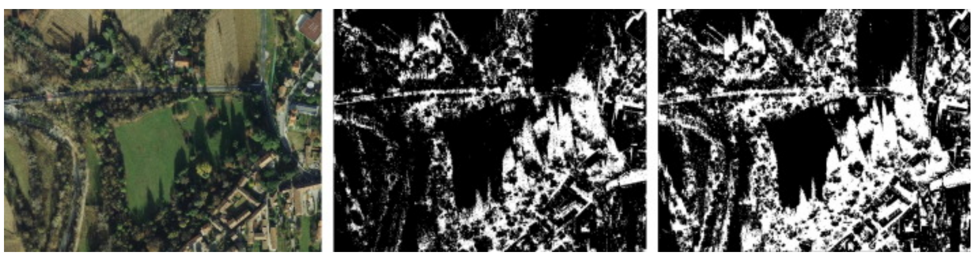

Figure 3.13: Comparison of WBI and PC1 and C3 new index with respect to the original image

Unfortunately the image of the entire municipality with 9 cm resolution was difficult to classify due to limits in the computation memory, this preclude the use of this kind of image resolution and it was necessary to resize the pixel from 9 to 90 cm resolution.

The resulting PC1+C3 shadow mask has been applied to the original entire image, and the result presented on Figure 3.14 shows the consistency of the problem previously discussed.

Figure 3.14: Shadow mask of Tavagnacco municipality

Shadow restoration

Image reconstruction by shadow removal is the second step in the proposed procedure. Several shadow mitigation approaches are present in literature, but most of them are not suitable for the automatic processing of large VHR images; the relevant user interaction and the inefficiency to handle irregular shadow and color patterns, typical of tree canopy, are the major drawbacks. Further solutions have been therefore investigated and tested to automatically restore brightness in shadow pixels.

An innovative proposal has been implemented and tested and a set of transformation models derived from the Procrustes analysis are applied: defining L (light) a $n \times 3$ matrix composed by the RGB bands of the n non-shadow pixels, and S (shadow), a $n \times 3$ matrix, of the corresponding n pixels in shadow, it is assumed the existence of a general transformation T ($n \times n$) for which the Equation 3.2 is :

$$L = T \cdot S \qquad (3.2)$$

Estimating the proper T, in an efficient way, represents the core of the problem: ObP and EAOP have been chosen, among other Procrustes methods (orthogonal Procrustes, extended orthogonal Procrustes, and oblique Procrustes with centering) after specific tests performed on different VHR aerial images, selecting areas where well identifiable surfaces appeared in shadow and in non-shadow conditions, and applying the various transformations to recover the shadow [110]. The oblique Procrustes without centering (ObP) presented into Equation 3.3 [65]:

$$L = S \cdot R \tag{3.3}$$

where R is computed like in the Equation 3.4:

$$R = (S^T \cdot S) - 1 \cdot S^T \cdot L \tag{3.4}$$

The extended anisotropic orthogonal Procrustes, has a fast convergent iterative computation [60]. In this model, the RGB color rotation matrix R is orthogonal and an independent scale factor is applied to each RGB component. After having initialized the scale factors vector as d = [1 1 1], the following quantities (Equations 3.5, 3.6, 3.7, 3.8) are repeatedly computed until convergence:

$$B = [S - 1 \cdot mean(S)^T]^T \cdot L \tag{3.5}$$

$$[V, D, W] = svd\,\{B \cdot diag(d)\} \tag{3.6}$$

$$R = V \cdot W^T \tag{3.7}$$

$$d = diag(B^T \cdot R)./diag([S - 1 \cdot mean(S)^T] \cdot S) \tag{3.8}$$

where 1 is a 1 × n auxiliary vector of all ones, V and W are eigenvector matrices, D is the eigenvalue matrix resulting from the singular value decomposition of the product B · diag (d), ./ represents the element-wise division, and diag() acts as the corresponding Matlab© function. The final Equation 3.9 is the following:

$$L_S = S \cdot diag(L) \cdot R^T + 1 \cdot g^T \tag{3.9}$$

where g derives from the Equation with n , total number of pixels, is given by n=1 · 1T [57].

$$g = (L - S \cdot diag(L) \cdot R^T)^T \cdot 1/n \tag{3.10}$$

To test the efficiency of the developed algorithms the Cholesky method, already employed in literature [99, 100], was chosen, whose form is reported below (Equation 3.11):

$$L = R \cdot S^T + g \cdot 1^T \tag{3.11}$$

	Entire image	Shadow areas
Original image	38.10%	17.85%
EAOP	63.02% (+24.92%)	62.06% (+44.21%)
Cholesky	63.07% (+24.97%)	64.03% (+46.18%)
ObP	65.64% (+27.54%)	63.33% (+45.48%)

Table 3.8: Agreement between the supervised and K-means classification of the original image (with shadows), and of the three de-shadowed for shadow areas and for the entire image

where R is directly computed by the Cholesky decomposition of the covariance matrices of S and L, g is a translation vector, and 1 is a $1 \times n$ vector of all ones.

In particular, ObP proves to be suited for half-light and irregularly textured conditions, while EAOP, by applying an individual scale factor to each RGB component, gives better results for uniformly cast shadows (see e.g. [9] about color scaling).

These techniques are well suitable for recovering shadows thanks to their ability to directly estimate coordinate transformations between point configurations indefinitely rotated, translated, and scaled.

The three algorithms used, produce corresponding images with a residual amount of shadows: some slight shadows still persist after the de-shadowing operation, despite being correctly detected; in any case the majority of shadows appear compensated or mitigated. Residual dark pixels are located at the original shadow borders, as a consequence of the high resolution and complexity of the image.

Table 3.8 illustrates again how the brightness restoration is a crucial and fundamental step to achieve a good classification.

Considering the entire municipality, EAOP, ObP, and the Cholesky methods have been used to generate three shadow-free images: the procedure of shadow restoration method was recently improved and re-classified using a previous unsupervised method of classification consisting of first classifying shadows and then non-shadow pixels into three main classes.

Identifying the exact correspondence between the classes can help in restoring the light in shadow pixels matching surfaces of the same nature (vegetation with vegetation, urban with urban and bare soil with bare soil). Figure 3.15 demonstrate that this new approach enhances the results and so improves the final classifications.

Figure 3.15: Images obtained after shadow removal by EAOP (up), Cholesky (center) and ObP (down) method

Image classification

After the shadow removal process, the three obtained shadow-free images have been individually classified using the K-mean unsupervised classification method. The previous experimental comparison [109]shows that classification results could be considerably different depending on the de-shadowing algorithm applied and from those results it is possible to choose the best classifier which was the k-means.

In a VHR image the essential information is contained in the red-green-blue color components (RGB) and in the texture, therefore a preliminary step in image analysis concerns the classification in order to detect pixels having similar characteristics and to group them in distinct classes. Common land use classification approaches use color at a first stage, followed by texture analysis, particularly for the evaluation of landscape patterns.

The procedures developed [110] considered the use of invariant color components, image re-sampling, and the evaluation of a RGB texture parameter for various increasing sizes of a structuring element: to identify the most efficient solution, the classification vectors obtained were then processed by a K-means unsupervised classifier using different metrics, and the results were compared with respect to corresponding user supervised classifications.

The experiments performed on other samples let us evaluate the effective contribution of texture information, and compare the most suitable vector components and metrics for automatic classification of very high resolution RGB aerial images.

As reported in previous studies [110] and illustrated in Table 3.9 only for the samples of 2011, results showed that significant classification improvements can been obtained after substituting RBG with CIELab, CIELuv, and C1C2C3 respectively[1], or by stretch-decorrelating the color bands. Generally, invariant parameters provide better classification results than those based on RGB. Furthermore, the introduction of texture information in the classification vector, or the application of a different clustering distance – Euclidean vs. cosine – does not appear to give effective improvements for the segmentation process.

Table 3.9 demonstrates that the classification of the area with a previous stretch-decorrelation of the bands gives the best classification results.

Landuse classifications of Tavagnacco municipality are reported in Figure 3.16 and Table 3.10 and 3.11 summarize the total amount of area of the five classes identified: grass, that include gardens but also some cultivated fields, urban areas that consist of industrial and civil building but also streets, bare soil and dark bare soil include fields that are not already ploughed and fields that are already tilled (have been ploughed), and finally high vegetation which includes areas with trees and also, possibly a single tree.

Based on the results and the previous studies the landuse map chosen is that derived from the ObP shadow reconstruction method and it is reported on Figure 4.24

[1] Definition of these indexes is reported in [110]

	M	1_@9	1@27	1@45	2@9	2@27	2@45	Mean	Med
RGB decor	E	69.15	85.80	72.42	71.47	76.67	67.53	73.84	71.95
LAB	E	68.99	86.59	69.89	71.55	74.17	68.35	73.26	70.72
LUV	E	68.98	85.33	68.95	72.89	76.38	68.92	73.58	70.94
RGB	C	68.81	75.53	73.66	67.68	74.72	67.57	71.33	71.24
C1C2C3	C	65.21	73.24	72.85	63.10	68.15	61.80	67.39	66.68
C1C2C3	E	66.76	73.45	72.65	64.07	69.43	62.31	68.11	68.10
HSV	E	63.72	83.38	68.17	73.18	73.92	68.54	71.82	70.86
RGBdecor	C	52.66	66.51	62.56	62.45	69.04	65.93	63.19	64.25
RGB+t3	C	69.41	66.32	61.71	67.67	68.61	58.26	65.33	67.00
R1G1B1	E	64.81	78.42	63.13	61.34	64.82	57.87	65.07	63.97
RGB	E	64.77	78.37	63.07	61.32	64.68	57.79	65.00	63.88
RGB+t3	E	65.20	77.46	61.92	61.63	63.28	66.46	65.99	64.24
RGB+t9	E	64.96	73.88	57.57	60.39	61.05	61.09	63.16	61.07
l1l2l3	E	45.31	51.01	60.01	53.47	51.18	56.56	52.92	52.33

Table 3.9: Agreement percentages between the various unsupervised K-means classifications of the different pixel components, and the supervised classifications assumed as reference. Column M specifies the metrics (E=Euclidean, C=cosine), Med. the median values, t3 and t9 for texture evaluation

%	Grass	Urban	Bare soil	Dark bare soil	High vegetation	Total
EAOP	20.97	21.46	28.56	16.57	12.41	100
Cholesky	21.27	15.27	26.67	35.98	0.79	100
ObP	21.12	21.39	28.44	16.56	12.47	100

Table 3.10: Percentage of the five identified classes

km^2	Grass	Urban	Bare soil	Dark bare soil	High vegetation	Total
EAOP	3.22	3.29	4.41	2.54	1.90	15.36
Cholesky	3.26	2.34	4.09	5.52	0.16	15.36
ObP	3.24	3.28	4.37	2.54	1.93	15.36

Table 3.11: Area (km^2) of the five identified classes

Figure 3.16: Classification results of the images obtained after shadow removal by EAOP (up), Cholesky (center) and ObP (down) method

Chapter 4

Design and choice phase

A model for achieving sustainable solutions in endogenous and exogenous areas has been designed with a holistic approach. This model allows to make a choice between systems that use different sustainable combinations of technologies. The ultimate goal is to create a tool that gives the opportunity to put the various actors with different roles in decision-making, in conditions to better understand how their actions can affect social, environmental and economic costs within the territory.

The outcomes can be considered an example of how the tool can be useful in decision making process, but the model can have a wide use due to the fact that there is a broad number of politics that can be adopted.

The model is based on the three characteristic phases of a DSS: investigative phase, design phase and decision phase. After having reviewed the data acquired, the multi-objective model has been structured and then applied. In order to have a better comprehension of how results have been reached, the conceptual model has been reported in Figure 4.1.

It should be noted that the thesis work has focused mainly on the first phase of the model because the spatial vision of it requires the elaboration of data from various sources, which often can not be directly integrated with each other. This allowed the identification of guidelines for the creation of environmental databases that can dialogue each other and to allow processing by the institutions in order to be useful for environmental monitoring.

Energy and environmental diagnosis have been developed with two approaches and in two directions: a classical approach to the identification of solutions that provides for the assessment of a single configuration chosen and a simulation.

The classic approach involves the identification of the territorial configuration and set the variables, a technical-economic evaluation is made for the environmental solution.

The simulation approach instead is divided into several steps. The first step is the identification of alternative scenarios that may be generated by the choice of the different technologies. For choice and scenario analysis, the Formative Scenario Analysis (FSA) was used, which provides for the creation of scenarios

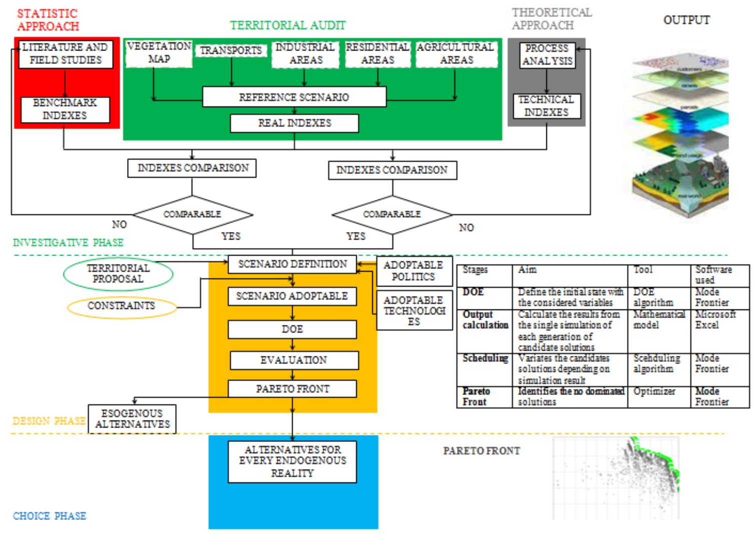

Figure 4.1: Conceptual model of the SDSS developed

by means of a factor analysis and a deletion of some of them thanks to the introduction of constraints such as, for example, the illogical conjunction of variables from a technical point of view or, as not meeting regulatory constraints.

4.1 Investigative phase

The first phase consists of two steps: a data collection and a processing and estimation of performance indices of the territory. In order to evaluate the performance of the territory these indices can be compared, on the one hand, with the theoretical energy ones derived from a theoretical approach or from European or national objectives and, with the other key environmental indices derived from industry or scientific literature which allows a first comparison with similar realities. The indices examined in the study are shown in the maps in Figure 4.15, 4.16 and 4.17.

The energetic performance indices can be divided into electrical IPE_{el} (Equation 4.1), thermal IPE_{th} (Equation 4.2) and total IPE_{tot} (Equation 4.3) which evaluate the energetic performances with reference to the single residential and industrial buildings.

$$IPE_{el} = \frac{E_{el}}{building_{res/ind}} \left[\frac{kWh_{el}}{inh/m^2}\right] \tag{4.1}$$

$$IPE_{th} = \frac{E_{th}}{building_{res/ind}} \left[\frac{kWh_{th}}{inh/m^2}\right] \tag{4.2}$$

$$IPE_{tot} = \frac{E_{tot}}{building_{res/ind}} \left[\frac{kWh_{tot}}{inh/m^2}\right] \tag{4.3}$$

Electrical consumption data E_{el} stated in kWh per residential or industrial building and their relative costs (in €) are directly provided from the municipality which has received them from “Agenzia delle Entrate” with the aim of verify local taxes.

Thermal energy E_{th}(Equation 4.4) stated as kWh was calculated as the output of the global performance of the boiler power from the j fuel η_{gj} (assumed to be 0,85 oil boiler e 0,9 for the methane one) and the amount of the j fuel m_j used by the residential and industrial buildings provided by “Agenzia delle Entrate” e H_i, calorific value of the j fuel.

$$E_{th} = \sum_j \eta_{gj} \cdot m_j \cdot H_{ij} \tag{4.4}$$

The total performance index, is given by the sum of thermal and electrical energy and is stated in toe per civil or industrial building.

As far as environmental indeces are concern the Water Consumption Index (IPW_o, calculated as in Equation 4.5) and waste production index (IPW_a, calculated as in Equation 4.6) were considered and reported in Figure 4.18 and 4.23. The first one considers the water consumption m_{H_2O} in m^3 in a municipality for single residential or industrial building. It is directly evaluated from the database of water management company. The second one evaluates the waste production considering the single residential or industrial building.

The industrial waste has not been considered into the elaborations of the model because companies waste are already minimized due to the fact that wastes are costs for them.

$$ICW_o = \frac{m_{H_2O}}{building_{res/ind}} \left[\frac{m^3}{inh/m^2}\right] \tag{4.5}$$

$$IPW_a = \frac{m_w}{building_{res/ind}} \left[\frac{t}{inh/m^2}\right] \tag{4.6}$$

For the territory characterization the green index (IG, calculated as in Equation 4.7) was defined. It represents the CO_2 absorption capacity for the analyzed territory. It is calculated as the relation between the area (a) cover by vegetation, trees, and gardens, and S the total area of the considered territory.

$$IG = \frac{a}{S} \tag{4.7}$$

The outputs of this first phase are the following:

- cluster Maps of the territory based on consumption and requirements that give the opportunity to identify possible actions in the area (Figures at the end of the chapter),

- identification of comparison indeces which can give a first approximation of the energetic and environmental performances of the area and can give a monitoring of the territory, if annually repeated. If environmental actions will be implemented, they can monitoring if results are in line with that awaited but, if not it is possible to suggest novel and better actions,
- visual identification of requirements and availability in order to plan the possible actions in the area.

4.2 Scenario analysis

The second phase considers the simulative approach that can be divided into various step. The first step is the identification of the possible scenario that can be adopted from the choice of different actions for politics execution.

For analysis scenario and choice the Formative Scenario Analysis (FSA) was used. The FSA involves scenario creation by means of a factor analysis and a deletion of some of them thanks to the introduction of constraints.

In the specific case, the adoption of a measure of energy or environmental improvement considerably influence the decision (two levels: presence or absence).

Nevertheless some values of these variables are not able to produce different scenarios. The number of possible levels assumed by the variables are n equal to the number of measures you want to implement on a territory. This generates a number of scenarios equal to 2^n. The 2^n scenarios are then reduced considering technical, economic and social constraints. As an example, the model was applied in the case of implementation of 5 measures (agreed with the local authority) in particular:

1. promote the efficiency improvements of residential and industrial buildings,
2. implementation of electricity production by the photo-voltaic *(in loco)*,
3. variation of waste collection method,
4. dismiss Euro 0 and 1 vehicles, in favor of more sustainable ones,
5. increase of green areas, despite of agricultural one.

So, in this case it is possible to have 32 scenarios.

The next step is the simulation phase itself which consists of 4 stages described in Figure 4.2., each of which can be done with different tools. In particular, in this case most of the stages is performed thanks to the use of Mode-FRONTIER ® software.

The four stages referred to:

1. initial DOE: in order to define the experiment,

2. scheduler: Multi-Objective Genetic Algorithms (MOGA–II) has been chosen as the optimization algorithms,
3. simulator parameters: a range of optimization parameters could have been chosen at this stage (in our case we chose 10.000 repetition of DOE and 500 of the algorithm),
4. finally, scenario analysis was considered.

Stages	Aim	Tool
DOE	Define the initial state with the considered variables	DOE algorithm
Output Calculation	Calculate the results from the single simulation of each generation of candidate solution	Mathematical model
Re-Scheduling	Variates the candidate solutions depending on simulation results	Scheduling algorithm
Pareto Front	Identifies the no dominated solutions	Optimizer

Figure 4.2: Structure of the phase

4.3 Design Of Experiment

The first stage involves the determination of what is the initial set of the population on which to perform the simulation and optimization operations. This step is defined by design of experiments (DOE) or the determination of what is the set of samples that constitute the initial population.

This instrument enables the provision of a number of individuals data by the combination of the different variables significant for the system, to use for a resolution of the first attempt of the algorithm. Based on the results obtained, it will change this population by isolating the most suitable individuals to achieve the objectives.

In the computations it was chosen to use the generation based on Sobol sequence, which allows the production of multiple sequences of parameters in order to be as uniform as possible in the multi-dimensional space. The big difference compared to the pseudo-random numbers is that the sampled values are chosen based on previous samples, so this allows to avoid the presence of aggregate points.

4.4 Mathematical model

The simulation approach involves the identification of a basic solution, for our purposes, it is given by the system solutions defined by the solution found with the classic method and a set of variables that are the most critical variables that can affect the choice of decision maker.

In this case the basic solution was implemented in Excel and then imported into modeFRONTIER® software.

The mathematical model also includes the identification of the most significant variables to be taken into account to describe the problem and the constraints which, the produced solutions, must comply.

The Mathematical model, calculating consumption, costs and possible toxicity associated with the UM considered process, makes possible to highlight (for comparison) between the different scenarios provided, those that allow a more distinct minimization of the environmental factor (Equation 4.8), of the investment costs (Equation 4.9), and of the social one (Equation 4.10).

$$E_n = minCO_{2eq} = \left| \sum_{ij} A_j \cdot FE_i \right| \tag{4.8}$$

where:

- i, considered emission;
- j, type of activity;
- A_{ij} activity index;
- $FE_{ij}$is the emission factor.

$$E_c = minC_{gs} = min \sum_h C_{gh} \tag{4.9}$$

where

h includes the costs for efficiency enhancement of buildings, PV, collection, treatment and disposal of wastes, fuel and management of systems costs.

$$S = min \sum_j \sum m_{amb,j} \cdot HTP_{amb,j} \tag{4.10}$$

where

- *j* is the type of pollutant,
- *amb* the environment considered,
- *m* the amount of the considered pollutant and
- *HTP* the Human Toxicity Potential coefficient.

To assess the social sustainability it was chosen to measure the well-being of the population; for this purpose it is chosen to minimize the toxicity in humans (objective 3).

For the definition of the objective functions of both CO_{2eq} and toxicity, the emission factors method was used.

The emission factor is the emission per unit of source activity, expressed, for example, as the quantity of pollutant emitted per unit of processed product, or as the quantity of pollutant emitted per unit of fuel consumed, etc.

Methane	MWh	%
Civil consumption	34.803	28,63
Industrial consumption	86.722	71,37
Total	121.525	100

Table 4.1: Distribution of civil and industrial methane consumptions. Source: [PAES]

Electricity	MWh	%
Civil consumption	15.960	26,34
Industrial consumption	44.627	73,66
Total	60.587	100

Table 4.2: Distribution of civil and industrial electricity consumptions. Source: [PAES]

The choice of the emission factors constitutes a critical aspect and presents few problems of reliability. In fact, the emission factors should be chosen based on the characteristics of the case, pulling the data from the technical and scientific literature in the field, and adapting bibliographic data to the particular application situation.

The emission factors used are those given in the classification SNAP 1997, developed by the EEA and adopted in Europe, which identifies 409 individual emission activities, and organizes them into 76 sectors and 11 macro sectors. Some factors are average (the road transport sector), others are derived from specific and timely reality.

The main source of reference emission factors is the European driving "Atmospheric Emission Inventory Guidebook" (EMEP / CORINAIR, 1999), others have been created in the international arena (IPCC), yet others come from the EPA (Environmental Protection Agency) of United States, where a precise European reference was not possible.

4.4.1 CO_2 emissions model for energy

In order to complete the database of energy consumption, the use of heating oil in the municipality has been estimated but it is not possible to identify the single use so this data cannot be georeferenciate and will be used only in the model evaluations.

From the PAES of Tavagnacco [PAES] it was possible to know the total amount of consumption of civil, and industrial and commercial buildings for electricity (Table 4.2), methane (Table 4.1), and heating oil (Table 4.3).

In order to determinate the total consumption of heating oil, first of all

Heating oil	MWh	%
Civil consumption	3.540	30,72
Industrial consumption	7.982	69,28
Total	11.522	100

Table 4.3: Distribution of civil and industrial heating oil consumptions. Source: [PAES]

	m^3	Conversion factor from $m^3$to MWh	MWh
Civil	4.188.026		44.602,477
Industrial	6.591.909	0,01065	70.203,83
Total	10.779.935		114.806,30

Table 4.4: Civil and industrial methane consumption (available data-set)

a check of the available data has been exploited. It is supposed that if the electricity and methane consumptions of PAES [PAES] and the available data-set will be comparable, it is possible to estimate the amount of buildings that used heating oil.

The methane consumption will be comparable after a transformation from m^3 to MWh: results in Table 4.4 with respect to Table 4.1 attests that the data-set are comparable.

The same hypothesis has been formulated for the electricity consumption: in order to compare the values reported in Table 4.2, a transformation should be elaborate.

Comparing Table 4.2 and Table 4.5 it is possible to assume that results can be again compared.

Based on the fact that the previous results are comparable, it is possible to derive the amount of building that used heating oil in the municipality using the Equation 4.11.

$$Q_{i,j} = H_j \cdot m_j \tag{4.11}$$

	kWh	MWh
Civil	15.493.800	15.493,8
Industrial	27.241.192	45.005,4
Commercial center	17.764.200	
Total	45.005.392	60.499,2

Table 4.5: kWh consumption of electric energy

Energetic class	Consumption per year
A	< 30 kWh/sq.m
B	30-50 kWh/sq.m
C	50-70 kWh/sq.m
D	70-90 kWh/sq.m
E	90-120 kWh/sq.m
F	120-150 kWh/sq.m
G	> 150 kWh/sq.m

Table 4.6: Energetic class classification

Electric Energy production	1998	2012	2015
Hydroelectric	19,89	15	16
Traditional thermoelectrical	79,4	73	67
Geothermoelectrical	1,6	1,87	3
Eolic	0,05	4,48	6
Photovoltaic	0,05	6,3	8

Table 4.7: Electric energy production in Italy: the fuel-shift

Where H_j is the calorific value, m_j is the mean consumption and $Q_j$is the heat.

Further, in order to understand the energetic class of the buildings of Tavagnacco, a spatial join with civic number and cadastral database was applied.

When the process was completed, the energetic class of each building was estimated based on their energetic consumption and the area of the buildings, based on the classification reported in Table 4.6. In the model, in order to promote the efficiency improvements of residential and industrial buildings the expedients taken into account were roof remake, insulation and window fixtures remake.

In order to evaluate CO_2 emissions deriving from electric energy consumption, the electric energy production methods were investigated.

In the recent years, Italy has conducted a fuel-shift has reported in Table 4.7, that has given a reduction of the CO_2 emissions.

In the baseline scenario in the considered year (2012) it was evident in Figure 4.3 the amount of electric energy production from traditional thermoelectrical methods.

As far as no-renewable energy production, the traditional thermoelectrical plants have been shift the fuel used from 1998 to 2015.

In Table 4.8 it was reported the main fuel used to produce electric energy: it shows the important decrease in the use of fuel oils and the increase of biomass during the recent years.

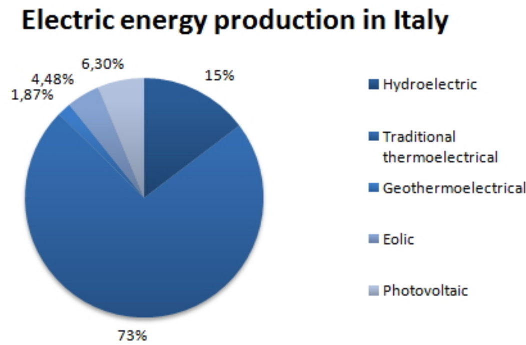

Figure 4.3: Energy typology production in Italy during 2012

Traditional thermoelectrical	1998	2012	2015
Methane	20	40	59
Carbon	11	11	21
Fuel oil	53	28	2
Biomass	0	3	11
Other	16	19	6.4

Table 4.8: Fuel used in the traditional thermoelectrical plants

4.4.2 CO_2 emission model for waste

Every type of waste has a different process (and as a consequence, a different recycle percentage) and a different cycle (Figure 4.4, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12) that should be take into account inside the model.

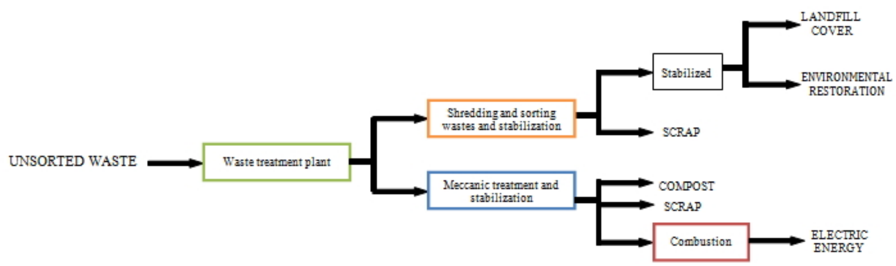

Figure 4.4: Cycle of unsorted waste

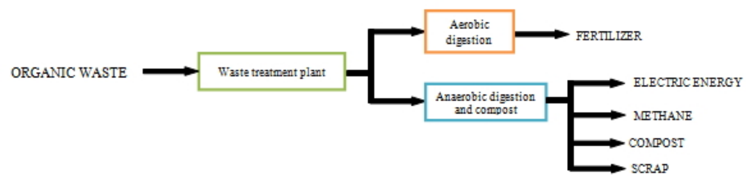

Figure 4.5: Cycle of organic waste

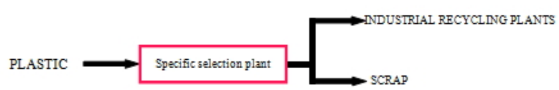

Figure 4.6: Cycle of plastic

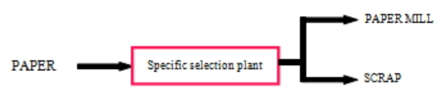

Figure 4.7: Cycle of paper waste

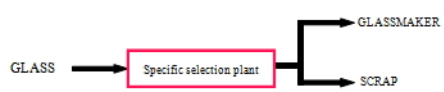

Figure 4.8: Cycle of glass waste

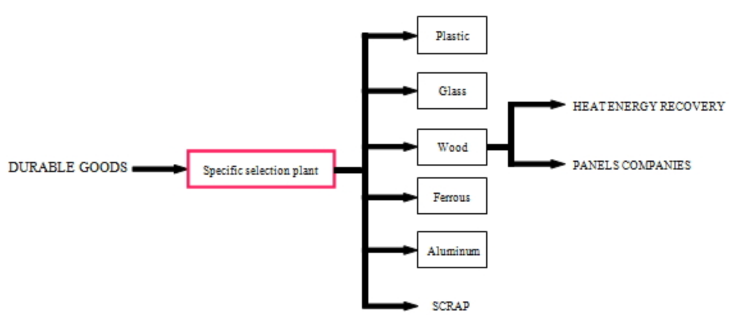

Figure 4.9: Cycle of durable goods

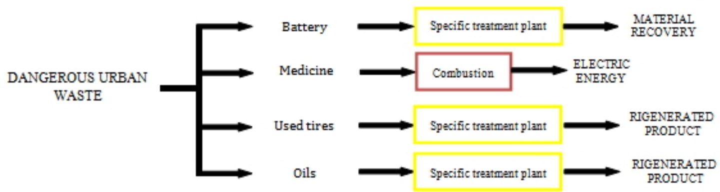

Figure 4.10: Cycle of dangerous urban waste

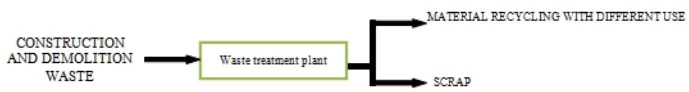

Figure 4.11: Cycle of construction and demolition waste

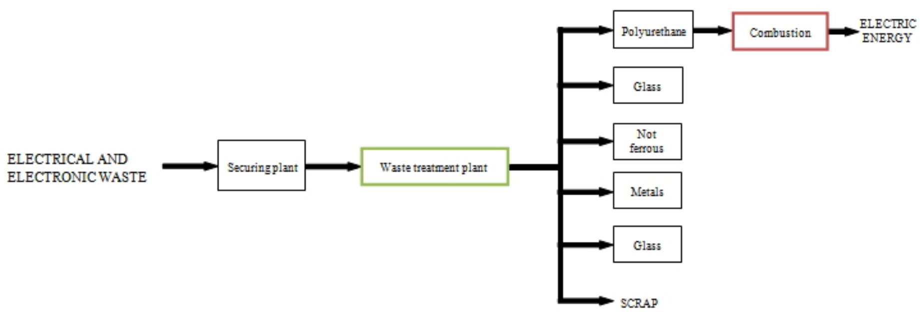

Figure 4.12: Cycle of electrical and electric waste

Transport is a vital element for most of the production processes and management and often the amount of energy linked to them is a significant part of the total energy expenditure in the process under consideration. The same report concerns therefore also the emissions resulting from these operations. As a consequence, it is important to evaluate not only the impact of the waste but also that of transport for the collection of them (Figure 4.13).

Data available for the elaborations, consider only the amount of kilometers traveled by the vehicles to pick up few typology of waste and not to bring them to the specific plant (Table 4.10).

As a first approximation it was decided to assign CO_2 emissions deriving from waste collection to every resident of the municipality.

For the organic waste, NET spa provided data on two collection of organic waste, one collection every week for inorganic waste and grass, and one collection every two weeks for plastic, paper and glass (Table 4.9).

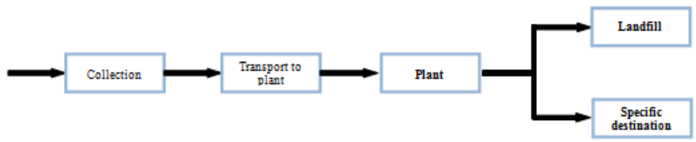

Figure 4.13: Destination of waste

Waste typology	Destination
Glass	Veritas (VE)
Plastic	Rive d'Arcano (UD)
Paper	Cartiera Romanello (UD)
Ferrous	Pittini or ABS-Osoppo (UD)
Nonferrous	Veritas (VE)
Wood	Bipan-Bicinicco (UD) or Fantoni-Osoppo (UD)
Durable goods	Friul Julia Appalti- (UD)
Electronic waste	
Exaust oils	
Construction and demolition waste	
Pneumatics	

Table 4.10: Waste destination in FVG

Waste typology	km for collections	km per year	l of diesel	km / resident
Organic waste	794	41288	16523,20	2,78
Inorganic waste	482	25064	10030,45	1,69
Green waste	450	23400	9364,53	1,58
Paper	338	8788	3516,90	0,59
Plastic and glass	338	8788	3516,90	0,59
Other fractions	0	0	0	0

Table 4.9: Impact of transport for waste collection

4.4.3 CO_2 traffic emissions model

In order to evaluate the total amount of CO_2 that a vehicle fleet can emit in a specific context the software open source COPERT 4 was used.

COPERT 4 needs to know the number of vehicles per typology that is reported in Table 4.11, age and fuel typology, reported in Table 4.12.

This data were acquired from a report of ACI [2011] where was reported the % of vehicle fleet at 31/12/2011 according to the first year of registration for the municipality of Udine; it was assumed that the same percentage exists also

Cars	Motor	Buses	Commercial v.	Special v.	Tractor	Total
12238	1621	0	1314	283	109	15565

Table 4.11: Number of vehicles per typology

in the municipality of Tavagnacco.

To fit with the previous traffic elaborations cars and motorcycles are aggregated into the class urban passengers vehicles instead the others are aggregated into the class heavy vehicles.

It was supposed that the type of vehicles that travel in the municipality is similar to the fleet of Tavagnacco.

In the case of road transport, the emission factor is expressed as the quantity of pollutant emitted per km traveled and vehicle (for example: g / km * VEH.) Or as the quantity of pollutant emitted per kg of fuel consumed (for example: g / kg of fuel). The Equation 4.12 was used:

$$P_{EUII_{tot}} = \sum_{i=1}^{n} P_{EUII_{ij}} \tag{4.12}$$

where:

- $P_{EUIItot}$ = total annual travelling of the all fleet,
- P_{EUIIi}= annual traveling of the i vehicle,
- n = number of vehicles.

Calculated the annual trips, it has been scheduled a spreadsheet which can calculate the pollutants emitted by road type and vehicle class. The formula implemented for these calculations is the following:

$$\frac{E_{ij}}{year} = \frac{A_{ij}}{year} \cdot FE_{ij} \tag{4.13}$$

where:

- E_{ij} emissions from vehicles with class i on the j type of road;
- i, vehicle class (Conventional, Euro I, Euro II, Euro III, Euro IV, Euro V);
- j, type of road (Highways, Urban and rural roads);
- A_{ij} activity index (in this case the distance traveled from the vehicles of class i on j type of road);
- $FE_{ij}$is the emission factor of the vehicles of class i on the j road type.

Year	Euro type	Age	Heavy vehicle	Motor cycles	Cars benzine	Cars gasoline	Cars other
2012	Euro 5	0-1	68	60	357	284	8
2011	Euro 5	1-2	90	63	349	260	52
2010	Euro 4	2-3	77	97	396	268	95
2009	Euro 4	3-4	111	86	409	340	34
2008	Euro 4	4-5	107	89	438	417	14
2007	Euro 4	5-6	104	75	376	385	10
2006	Euro 4	6-7	102	76	376	374	8
2005	Euro 3	7-8	92	75	357	360	5
2004	Euro 3	8-9	99	73	428	265	4
2003	Euro 3	9-10	104	66	488	206	4
2002	Euro 3	10-11	89	76	497	134	6
2001	Euro 3	11-12	72	96	509	94	9
2000	Euro 2	12-13	65	58	454	66	7
1999	Euro 2	13-14	48	41	440	42	8
1998	Euro 2	14-15	41	24	398	25	5
1997	Euro 2	15-16	39	15	258	18	5
1996	Euro 2	16-17	38	16	218	10	4
1995	Euro 1	17-18	22	15	187	7	3
1994	Euro 1	18-19	19	15	152	5	2
1993	Euro 1	19-20	27	19	160	8	3
1992	Pre- Euro	over 20	293	486	998	100	39
		TOTAL	1708	1621	8244	3669	325

Table 4.12: Number of vehicles and Euro typology in relation to age

4.5 Optimization algorithm

The optimization algorithm has the aim to select the population produced on the basis of the generated problem solutions, classify them according to a hierarchy of affinities with the objectives of the problem and finally determine which can be reproduced.

The optimization algorithm used in this work for multi-objective decision making among candidates solutions is part of the Evolutionary Algorithms (EAs) that are widely used in several optimization problems that are too complex to be solved by traditional methods [rigoni].

The Evolutionary Algorithms (EA), meta-heuristic optimization algorithms based on the characteristics of the population that use biologically inspired mechanisms, such as mutation, recombination (crossover), the natural selection and the survival of the strongest; this in order to refine, iteratively, the selection of possible solutions to the problem. As said, EA are based on biology, especially on the laws of ”natural selection” and ”survival of the fittest” produced by Darwin. The work cycle of an evolutionary algorithm is performed using the following steps:

- initially it creates a population of individuals having a random genome,
- by implementing these individuals within models of calculation you obtained by the determination of the value assumed by the objective functions,
- through the objective functions it is assigned to each candidate solution as suitable value for the solution of the problem,
- following the selection process, in which the solutions are filtered to allow the entrance of the playback section with higher probability,
- on playback, you can create a new set of individuals by varying or combining the genotypes of selected ones,
- in the absence of further guidance, it iterates the process starting from the second step.

The particular advantage in using evolutionary algorithms is that the method adopted allows to solve the problem without the need to provide a large number of information on the objectives, guaranteeing the possibility of resolving with good performance a good number of categories of problems.

The set of all vectors that respect the rule of Domain according to Pareto, are defined feasible solutions of the problem, or even, Pareto Front.

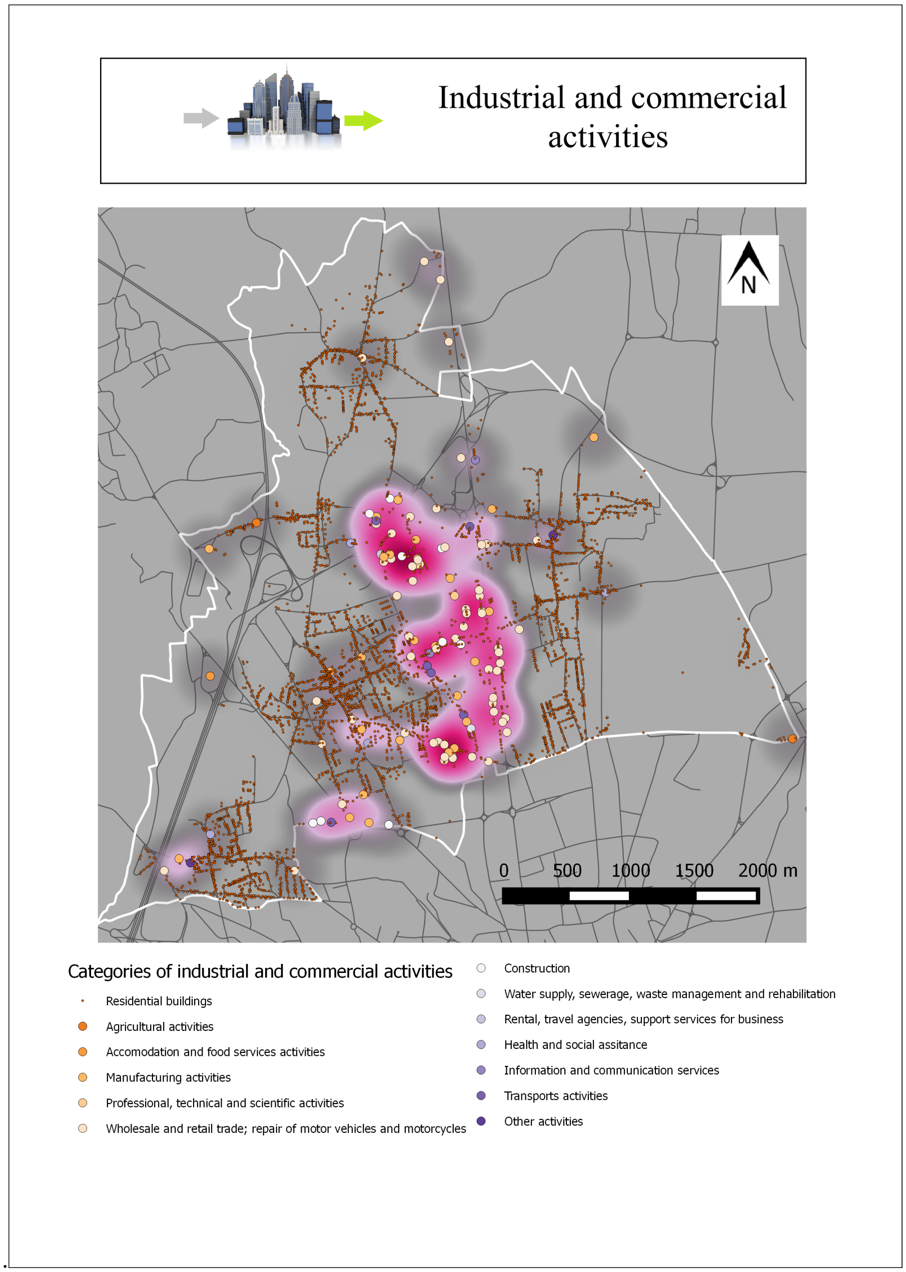

Figure 4.14: Map of industrial and commercial activities

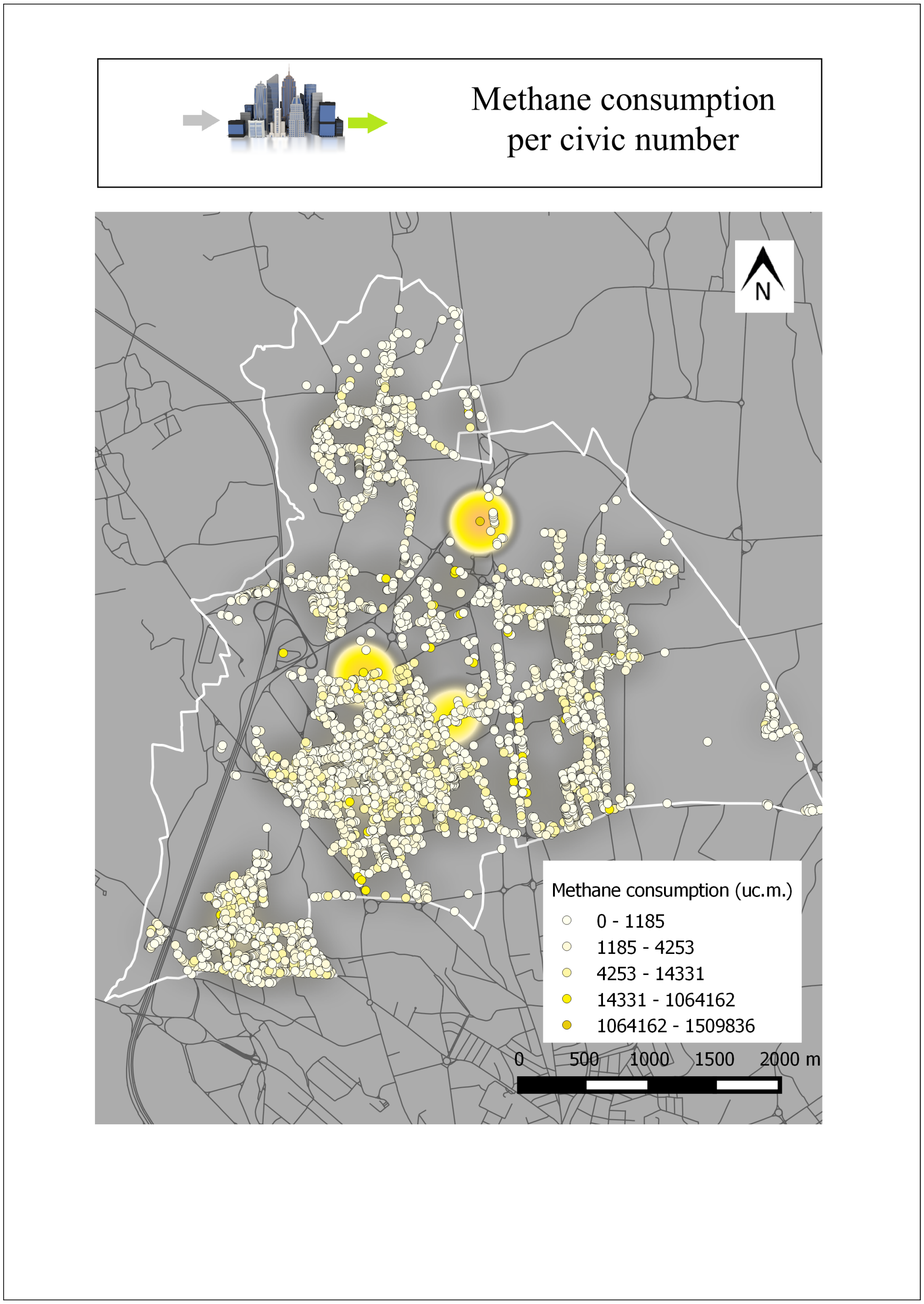

Figure 4.15: Energy (methane) consumption map

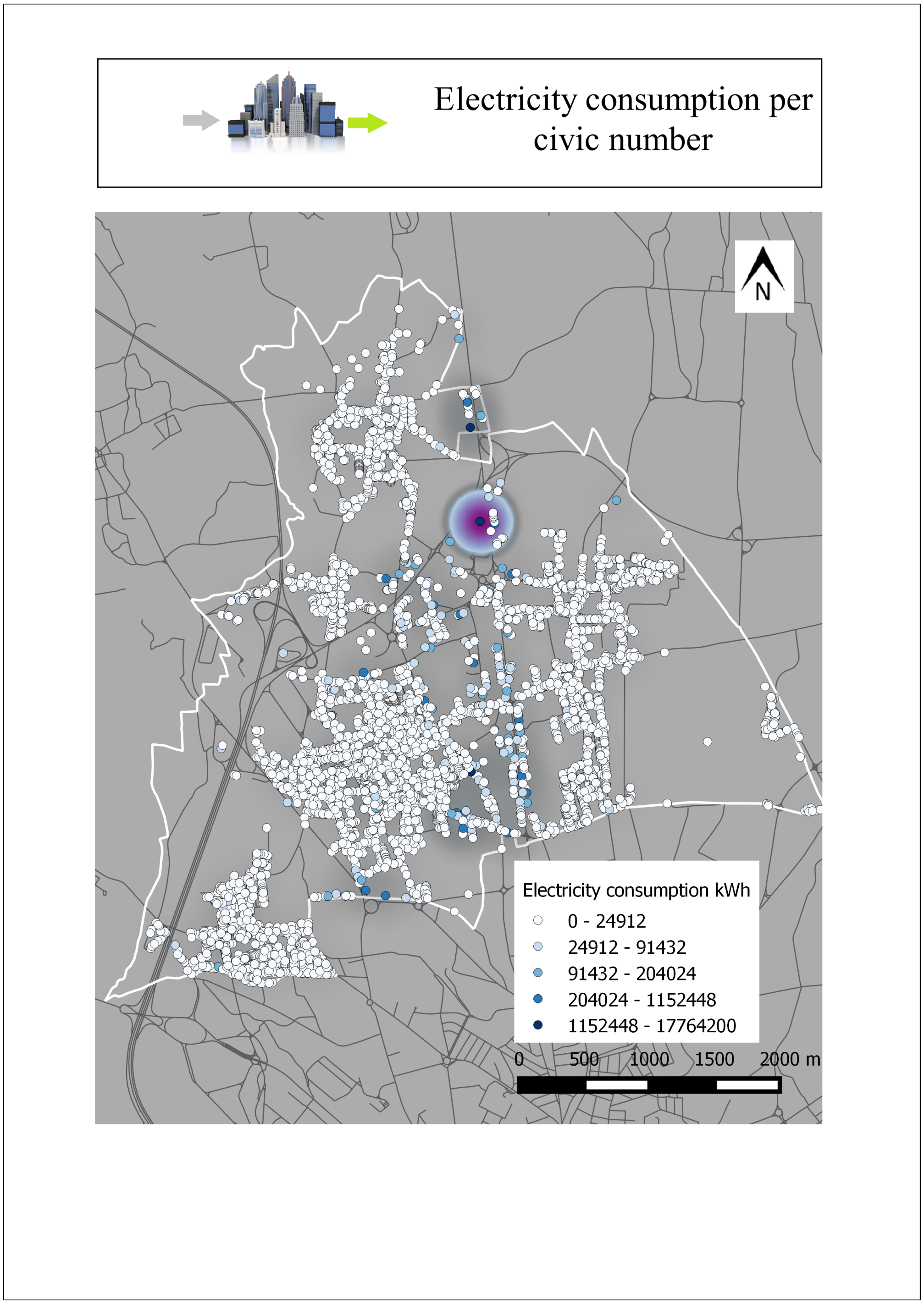

Figure 4.16: Electricity consumption map

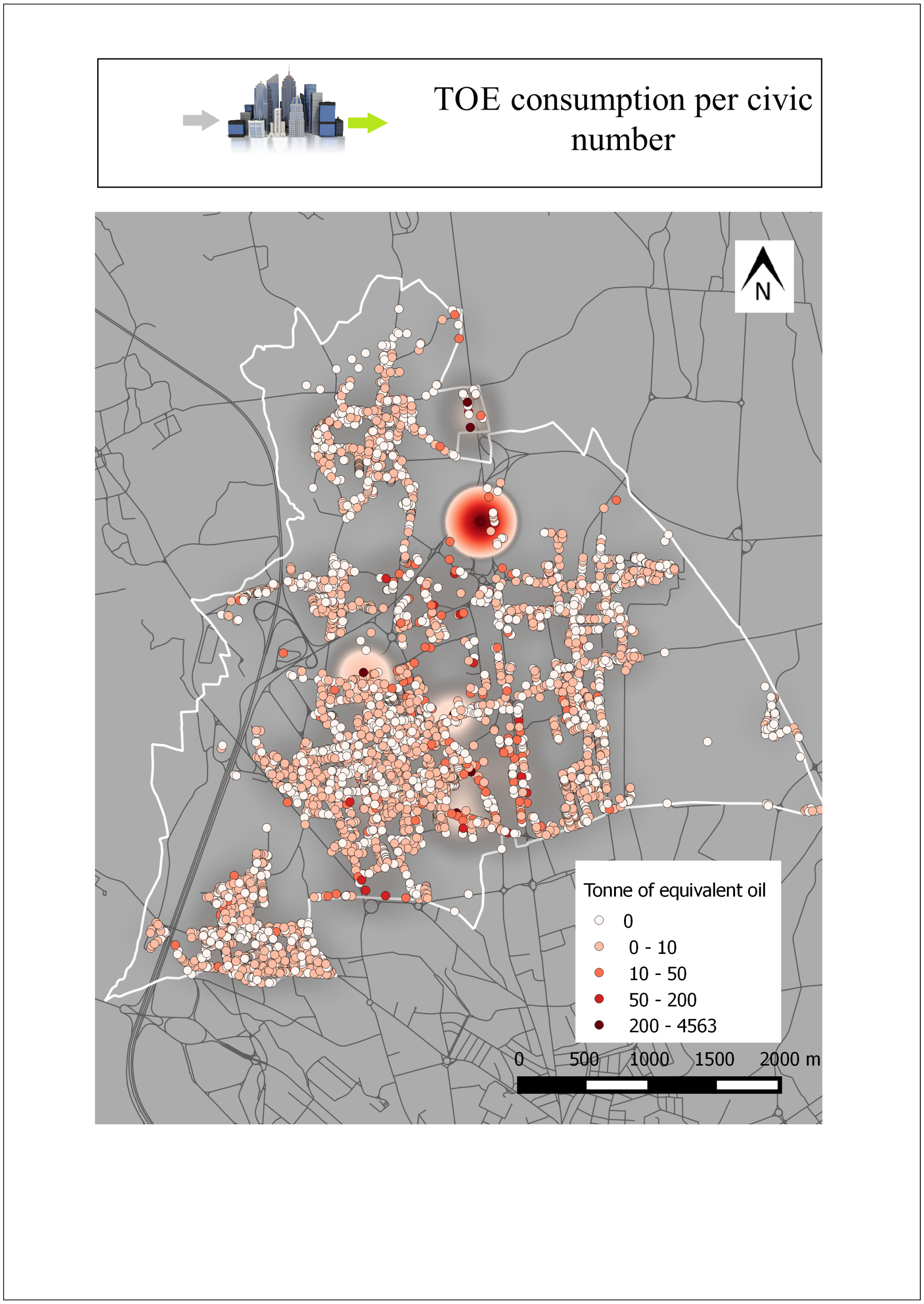

Figure 4.17: Energy consumption - toe evaluation

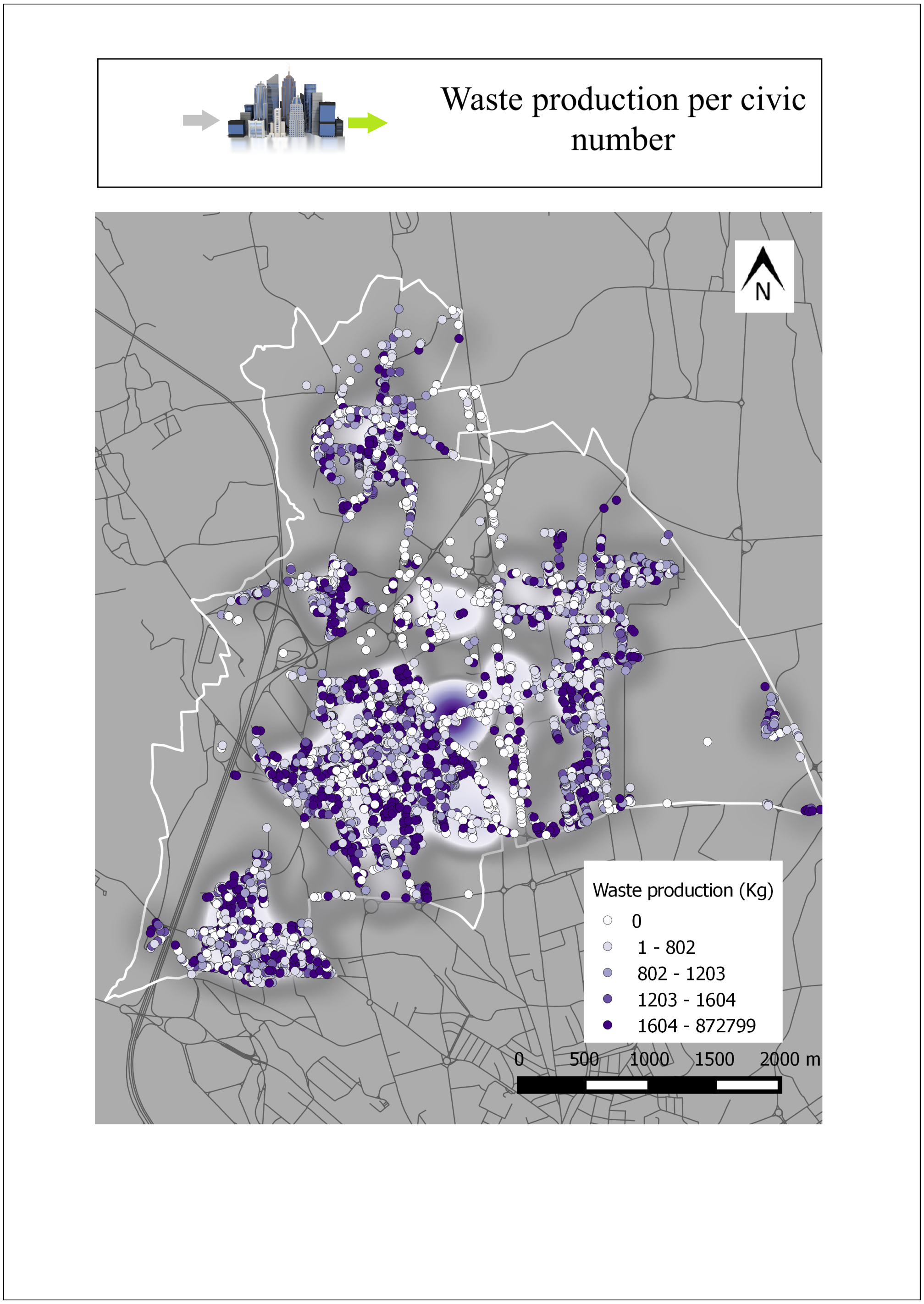

Figure 4.18: Waste production

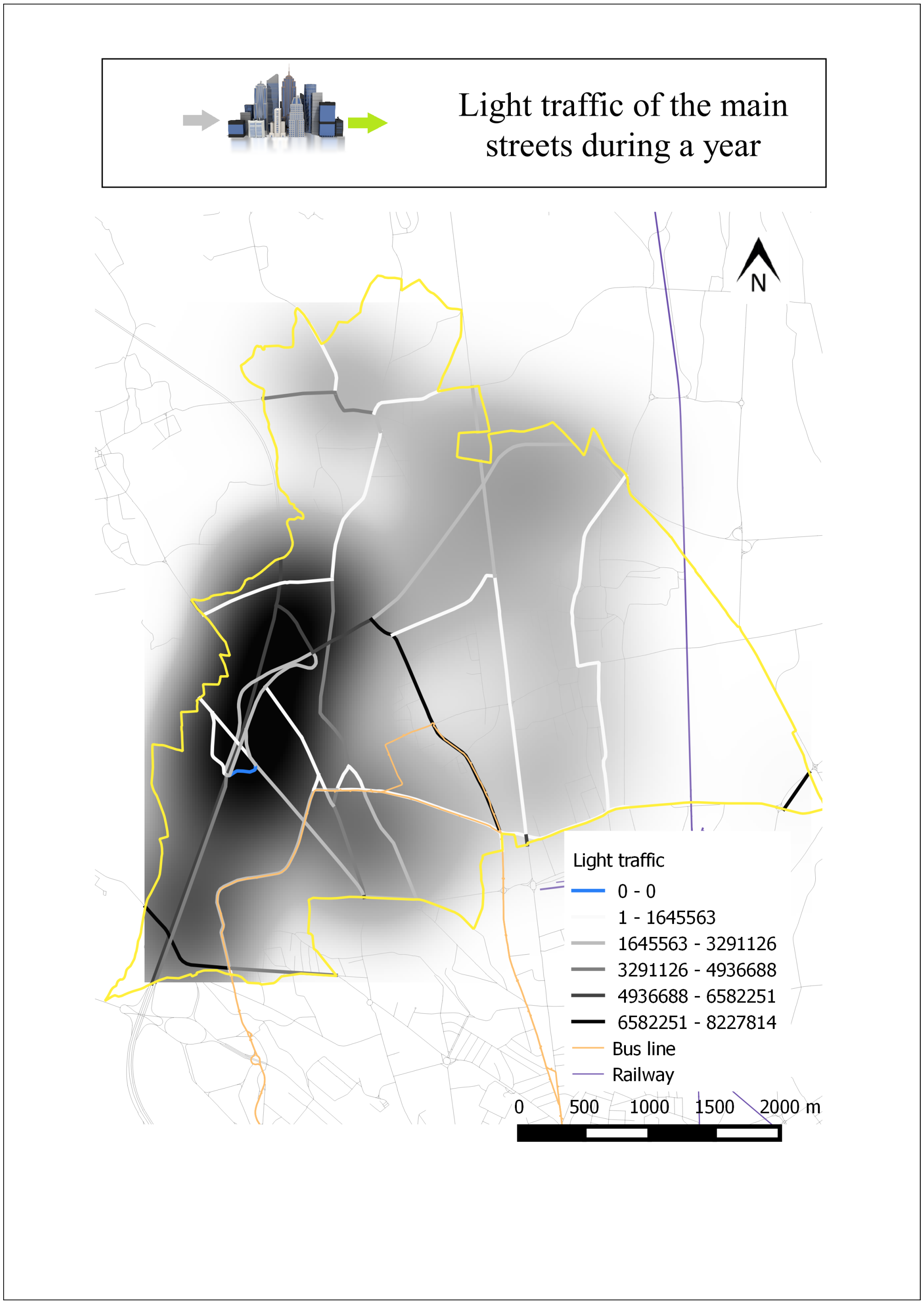

Figure 4.19: Light traffic of the main streets of Tavagnacco

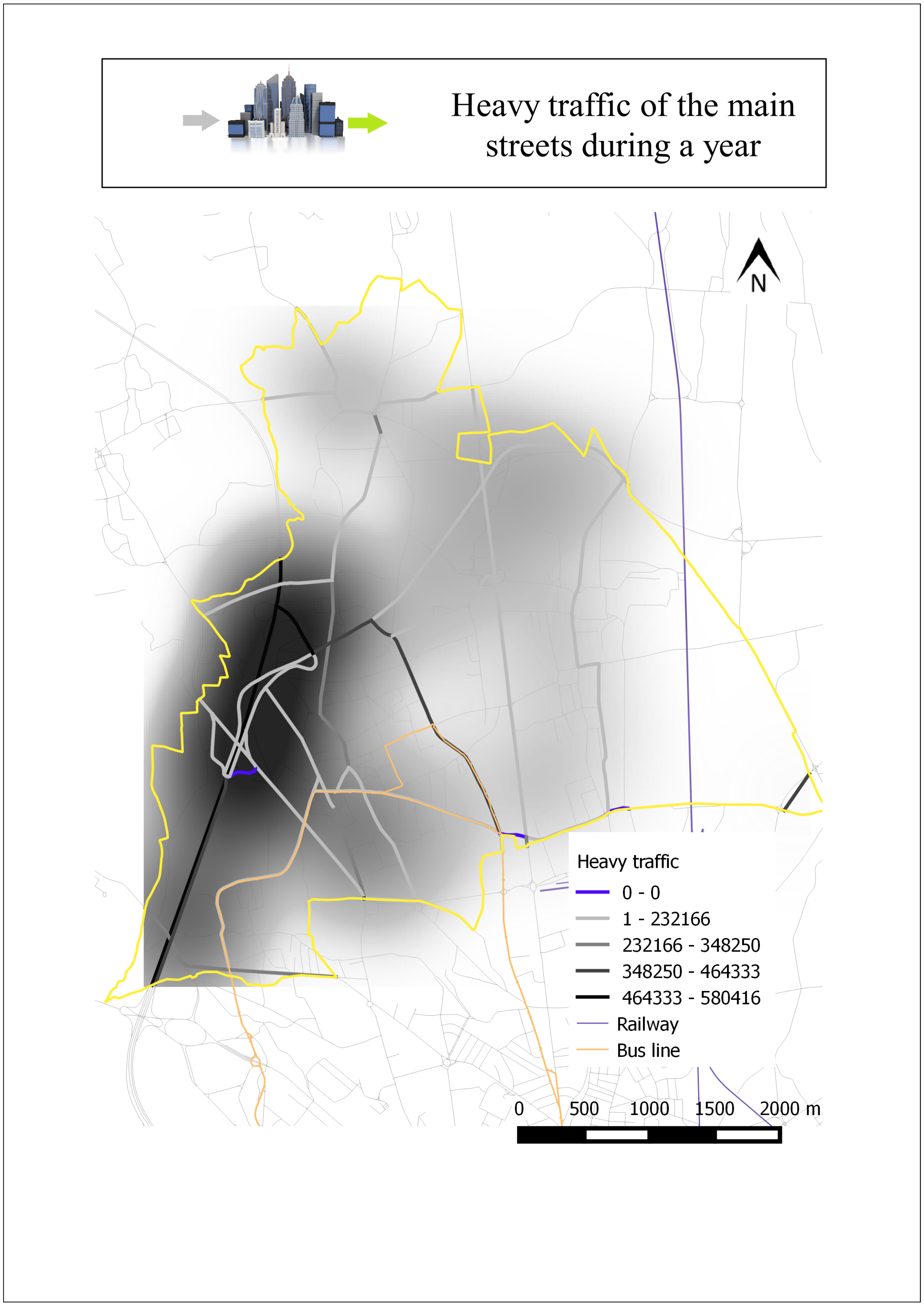

Figure 4.20: Heavy traffic of the main streets of Tavagnacco

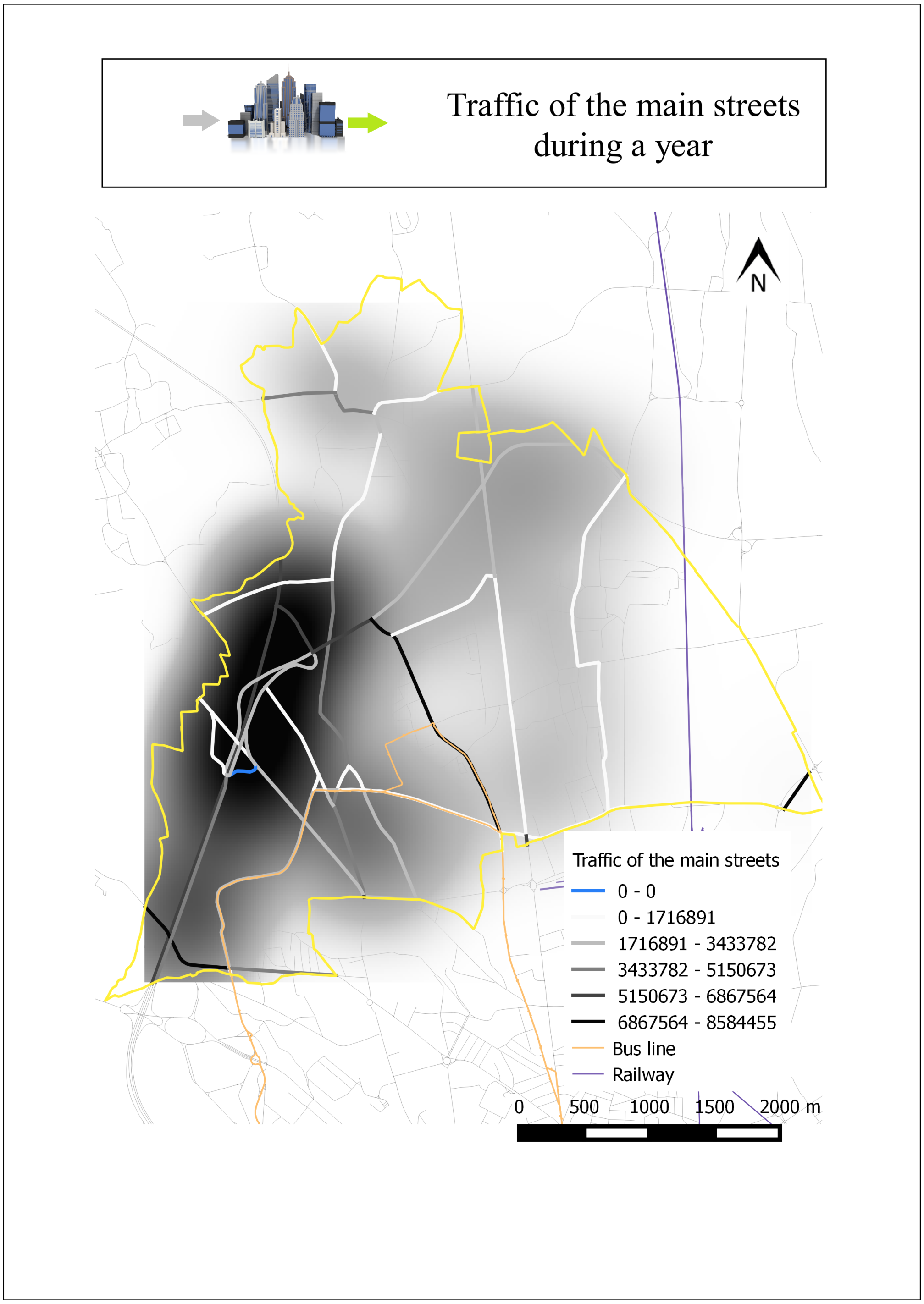

Figure 4.21: Traffic of the main streets of Tavagnacco

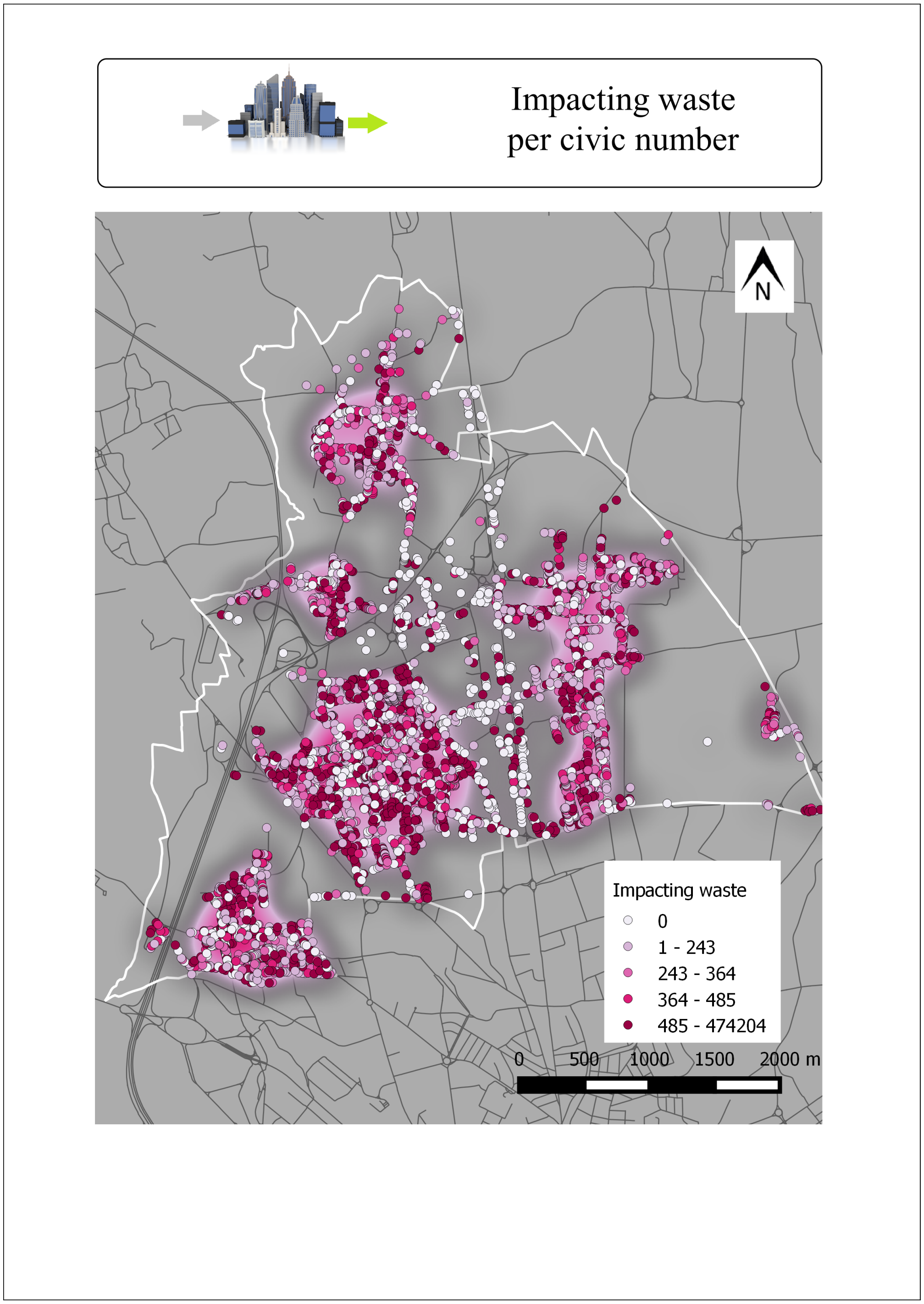

Figure 4.22: Impacting waste

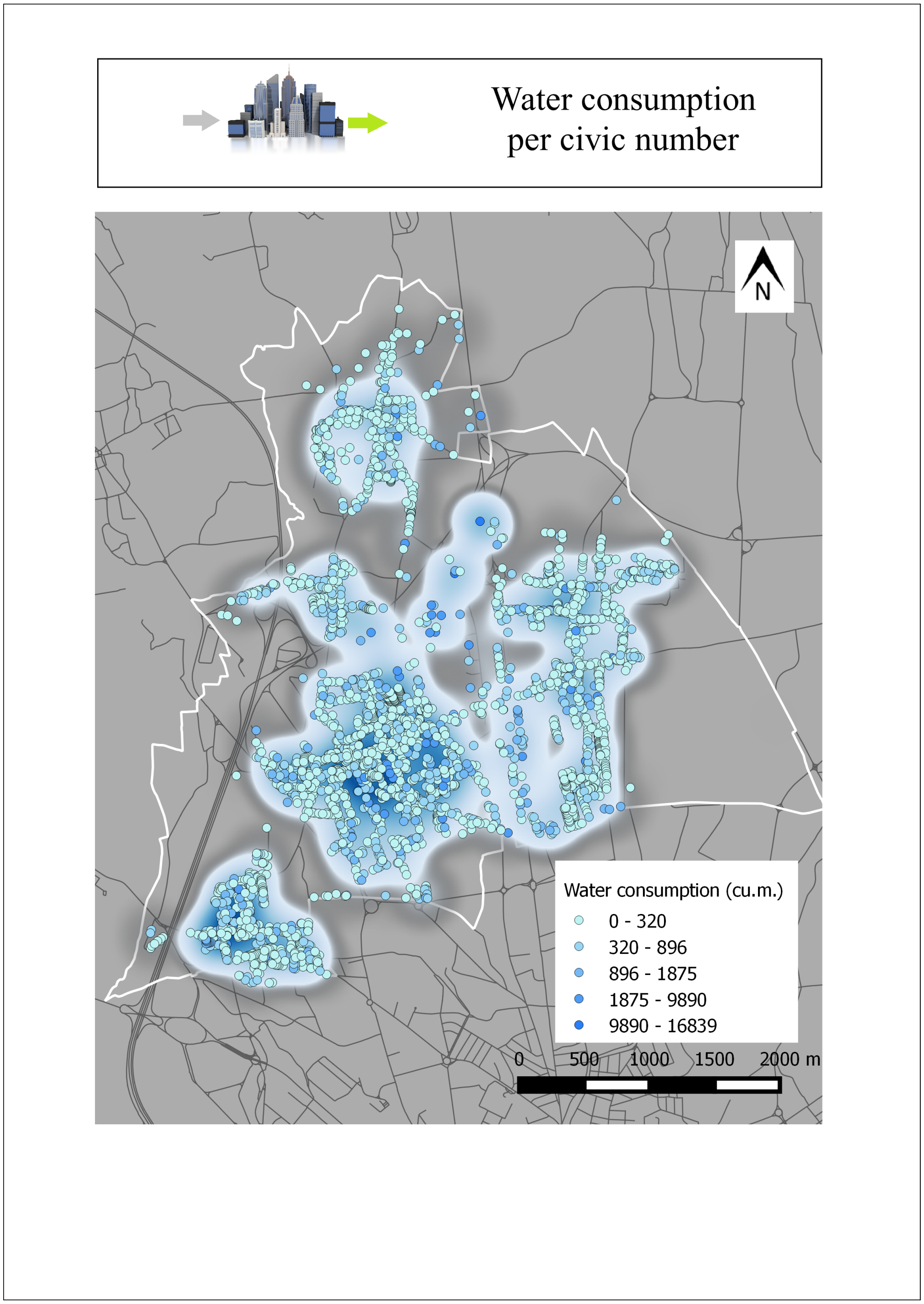

Figure 4.23: Water consumption

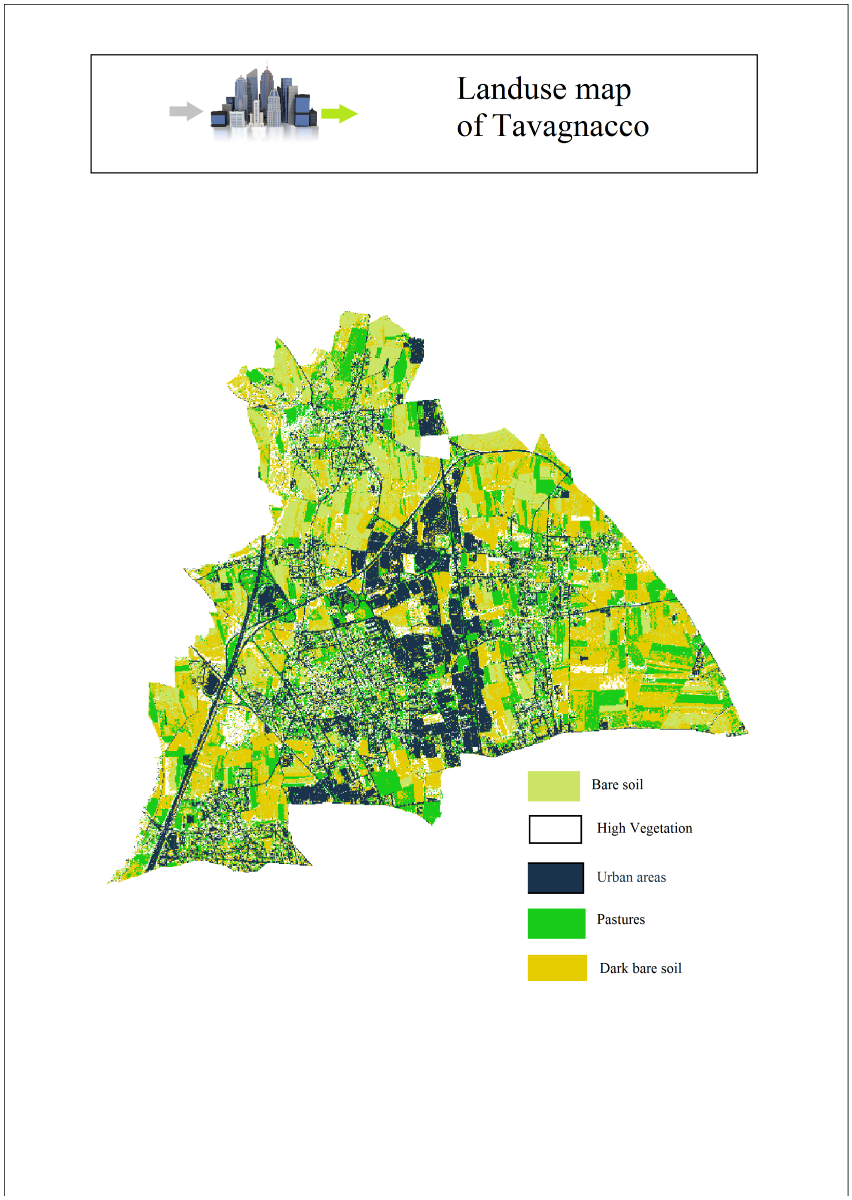

Figure 4.24: Landuse map

Chapter 5

Conclusions

In this study a new methodology to evaluate possible low carbon strategies was developed.

This method takes advantage from its flexibility: it is possible to evaluate CO_{2eq} impacts of emissions from the point of view of production chain (specifically for waste and traffic and electrical energy) and also from the sector one (civil, industrial and transports).

These hybrid model include both spatially dynamic and sector data inside the Urban Metabolism of a municipality with the aim to integrate sustainability, ecosystem services and eco-health as suggest from Chen et al. [2014].

The model has been applied to five possible measures and it is useful for the municipality to highlight how the measures about improvements efficiency of residential and industrial buildings is the first one that can give a first significant improvement in reducing CO_{2eq} emissions.

The increase of green areas (with vegetation and trees) can mitigate the environmental impact of CO_{2eq} emissions but can not compensate it as there are no agricultural areas that can balance the impacts resulting from human activities.

The simulations show that the implementation of electricity on site by photovoltaic system would improve the environmental impact if adopted in all the housing, allowing for a reduction of the electricity needs from traditional sources by 3% with respect to the actual needs.

The measure of efficiency of the vehicle fleet offers significant environmental, energy and social improvements of 11% with respect to the parameters of the actual fleet. It would be important to assess that not only the efficiency of the fleet but also of the fuel switching (ex.methane) that generally have better environmental performance than existing ones, but currently have limited distribution logistics.

In the waste sector instead the different material collected does not compensate for the economic, environmental and social costs of transports needs. It is therefore considered useful to push different types of waste collection as the local deficit makes a situation not feasible, and it is considered necessary to promote the collection of the organic material for energy production and separating the paper while the remaining waste materials can be recovered together. The implementation of this measure involves a global improvement of 3-4% with respect to the actual waste collection.

Not all energy improvements of buildings are sustainable from an environmental, economic and social point of view but it is necessary to consider the improvements of the energy classes of buildings E and F and with the suggested measures they can be brought in C and D classes.

In a context of limited budget we have been chosen to implement and represent the measure that allows the best energetic, social and economic performances.

As an example highlight the current status (Figure 5.1) and the results obtained after the implementation of the measure (Figure 5.2).

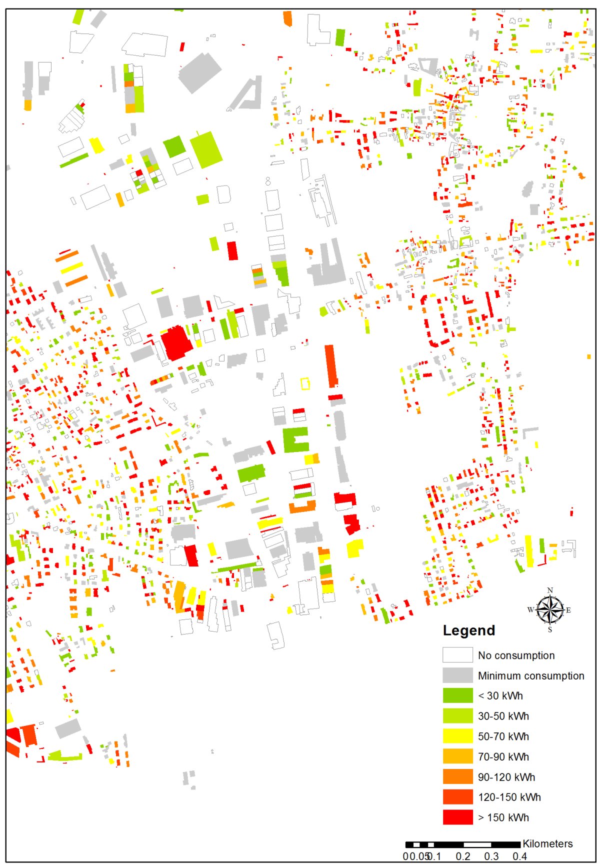

Figure 5.1: Energetic class of Tavagnacco buildings

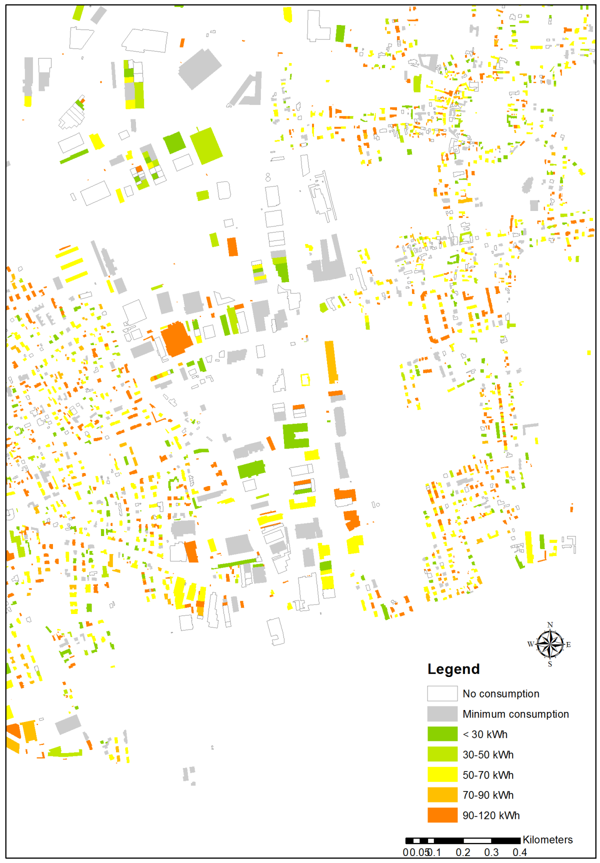

Figure 5.2: Energetic class of Tavagnacco buildings after energetic measures

Finally, despite of the difficulties in finding data, a set of different data deriving from various authorities was used; for the purpose of extend the study area but also to not waste time it is important that in the future there will construct a structure to find and organize useful data-set. From the analysis of the necessary database for implementing the model a simple expedient to do is to enable these database to use the civic number as reference key so, in this way all the database could easily communicate with each other.

Bibliography

[1] Abou-Abdo T., Davis N., Krones J., Fernandez J.E., 2011. Dynamic Modeling of Singapore's urban resource flows: historical trends and sustainable scenario development. In: International Symposium on Sustainable Systems and Technology (ISSST), Chicago, Illinois.

[2] ACI (Automobile Club d'Italia), 2011. Analisi dell'anzianità del parco macchine in Italia.

[3] Adeline K.R.M., Chen M., Briottet X., Pang S. K., Paparoditis N., 2013. Shadow detection in very high spatial resolution aerial images: A comparative study. ISPRS Journal of Photogrammetry and Remote Sensing 80 (2013) pp. 21-38.

[4] Alberti M., 1996. Measuring Urban Sustainability. Environmental Impact Assessment Review, 16: 381-424.

[5] Almeida A.M., Ben-Akiva M., Pereira F.C., Gauche A., Guevara C.A., Niza S., Zegras C., 2011. The Virtual City with Real Decisions: ITEAM. Proceedings of 7VCT, Lisbon, Portugal, 11-13 October 2011.

[6] Alter S.L., 1980. Decision support systems: Current practice and continuing challenges. Addison-Wesley, Reading, Massachusetts.

[7] Arampatzis G., Kiranoudis C.T., Scaloubacas P., Assimacopoulos D., 2004. A GIS-based decision support system for planning urban transportation policies. European Journal of Operational Research 152, 465–475

[8] Arevalo V., Gonzales J., Ambrosio G., 2008. Shadow detection in colour high-resolution satellite images. International Journal of Remote Sensing. Vol.29, No. 7, 10 April 2008, pp. 1945-1963.

[9] Arbel E., Hel-Or H., 2007. Texture-Preserving Shadow Removal in Color Images Containing Curved Surfaces. CVPR, 2007, IEEE Conference on Computer Vision and Pattern Recognition, pp. 1-8, doi:10.1109/CVPR.2007.383081.

[10] Ascione M., Campanella L., Cherubini F., Ulgiati S., 2009. Environmental driving forces of urban growth and development: An emergy-based assessment of the city of Rome, Italy. Landscape and Urban Planning 93, 238-249.

[11] Baccini P., 1997. A city's metabolism: Towards the sustainable development of urban systems". Journal of Urban Technology, 4 (2), 27-39.

[12] Baccini P., Brunner P.H„ 1991. Metabolism of the Anthroposphere. Springer Verlag, Berlin (1991).

[13] Baggio R., Caporarello L., 2005. Decision Support System in a Tourism Destination: Literature Survey and Model Building. Itais 2005.

[14] Bai X., 2007. Industrial ecology and the global impacts of cities. Journal of Industrial Ecology, 11 (2), 1-6.

[15] Barles S., 2007. A material flow analysis of Paris and its region. Renewables in a changing climate-innovation in the built environment. In: Proceedings of the International Conference CISBAT 2007. École Polytechnique Fédérale de Lausanne, Lausanne, pp. 579e584. 4e5. September 2007.

[16] Barles S., 2009. Urban metabolism of Paris and its region. Journal of Industrial Ecology 13 (6), 898-913.

[17] Becker J., 2004. Making sustainable development evaluations work. Sustainable Development 12(4): 200-211.

[Blaschke] Blaschke T., 2006. 'The role of the spatial dimension within the framework of sustainable landscape and natural capital'. Landscape and Urban Planning 75: 198–226.

[19] Blecic I., Cecchini A., Falk M., Marras S., Pyles R.D., Spano D., Trunfio G., 2014. Urban metabolism and climate change: A planning support system. International Journal of Applied Earth Observation and Geoinformation 26(1): 447-457. February 2014 DOI: 10.1016/j.jag.2013.08.006.

[20] Bhaskaran S., Devi S., Bhatia S., Samal A., Brown L., 2013. Mapping shadows in very high-resolution satellite data using HSV and edge detection techniques. Applied Geomatics December 2013, Volume 5, Issue 4, pp. 299-310.

[21] Brauckmann A., Mayr A., 2013. Regional Effects of Urban Planning – an Informal GIS Tool to Support Sustainable Strategic Planning. Proceedings REAL CORP 2013 Tagungsband 20-23 May 2013, Rome, Italy. http://www.corp.at ISBN: 978-3-9503110-4-4 (CD-ROM); ISBN: 978-3-9503110-5-1 (Print) Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE, Pietro ELISEI.

[22] Brown M.T., Ulgiati S., 2004. Emergy Analysis and Environmental Accounting, Encyclopedia of Energy, Vol 2: 329-354.

[23] Brunner P., 2007. Reshaping Urban Metabolism. Journal of Industrial Ecology, 11 (2), 11-13.

[24] Burstein F., Holsapple C.W., 2008. Handbook on Decision Support System 1. Springer.

[25] Campbell D., Brandt-Williams S.L., Meisch M.E.A., 2005. Environmental accounting using Emergy: Evaluation of the State of West Virginia.

[26] Canadell J. G., Le Que´re´ C., Raupach M. R., Field C. B., Buitenhuis E. T., Ciais P., Conway T. J., Gillett N. P., Houghton R. A., Marland G., 2007. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. PNAS 104:18866-18870. doi:10.1073pnas.0702737104.

[27] Castan Broto V., Allen A., Rapoport E., 2012. Interdisciplinary perspectives on urban metabolism. J. Ind. Ecol. 16, 851–861, http://dx.doi.org/10.1111/j.1530- 9290.2012.00556.x.

[28] Cavalett O., Ferraz de Queiroz J., Ortega E., 2004. Emergy assessment of integrated production systems of grains, pig and fish in small farms in south Brazil. In Ortega, E. & Ulgiati, S. (editors): Proceedings of IV Biennial International Workshop "Advances in Energy Studies". Unicamp, Campinas, SP, Brazil. June 16-19, 2004. Pages 239-256.

[29] Chen G.Q., Guo S., Shao L., Chen Z.M., 2013. Three-scale input–output modeling for urban economy: carbon emission by Beijing 2007. Commun Nonlinear Sci Num Simulat 2013;18(9): 2493–506.

[30] Chen S., Chen B., 2012. Network environ perspective for urban metabolism and carbon emissions: a case study of Vienna, Austria. Environ. Sci. Technol. 46 (8), 4498-4506.

[31] Chen S., Chen B., 2015a. Sustainable Urban Metabolism. Encyclopedia of Environmental Management.

[32] Chen S., Chen B., 2015b. Urban energy consumption: Different insights from energy flow analysis, input–output analysis and ecological network analysis. Applied Energy 138 (2015) 99-107.

[33] Chen S., Chen B., Fath B.D., 2014. Urban ecosystem modeling and global change: Potential for rational urban management and emissions mitigation. Environmental Pollution 190 (2014) 139-149. http://dx.doi.org/10.1016/j.envpol.2014.03.032.

[34] Chester M., Horvath A., 2010. Life-cycle assessment of high-speed rail: the case of California. Environ. Res. Lett., Vol. 5, 014003.

[35] Chrysoulakis N., 2008. Urban metabolism and resource optimisation in the urban fabric: the BRIDGE methodology. In: Proceedings of EnviroInfo2008: Environmental Informatics and Industrial Ecology, September 10e12, vol. 1. Leuphana University of Lüneburg, Germany, pp. 301-309.

[36] Chrysoulakis N., Lopes M., San José García R., Mills G., 2013. Sustainable urban metabolism as a link between biophysical sciences and urban planning: the BRIDGE project. Landsc. Urban Plan. 112, 100-117.

[37] Churkina G., 2008. Modeling the carbon cycle of urban systems. Ecol. Model. 216, 107-113.

[38] Cerreta M., De Rosa F., Di Palma M., Inglese P., Poli G., 2013. A Spatial Multicriteria Assessment Decision Support System (SMCA-DSS) for East Naples: Towards a Water Opportunity Map. Chapter Computational Science and Its Applications – ICCSA 2013 Volume 7974 of the series Lecture Notes in Computer Science pp 572-586.

[39] Daniell K.A., Sommerville H.C., Foley B.A., Maier H.R., Malovka D.J., Kingsborough A.B., 2005. In: Zerger, Andre, Argent, Robert M. (Eds.), Internationa Congress on Modelling and Simulation: Modelling and Simulation Society o Australia and New Zealand, December 2005, pp. 2026-2032.

[40] de Almeida A.M., Ben-Akiva M., Pereira F.C., Ghauche A., Guevara C.A., Niza S., Zegras C., 2009. A framework for integrated modeling of urban systems. In: 45th ISOCARP International Congress, Porto, Portugal, pp. 18-22.

[41] Decker E.H., Elliott S., Smith F.A., Blake D.R., Rowland F.S., 2000. Energy and material flow through the urban ecosystem. Annual Review of Energy and the Environment, 25, 685-740

[42] Deelstra T. and Girardet H., 2000. Urban agriculture and sustainable cities. In Growing Cities, Growing Food: Urban Agriculture on the Policy Agenday; Bakker, N., Dubbeling, M., Gundel, S., Sabel-Koschela, U., de Zeeuw, H., Eds.; Deutsche Stiftung fur Internationale Entwicklung (DSE): Feldafing, Germany, 2000; pp. 43-65.

[43] Delgado-Ramos G.C., 2015. Water and the political ecology of urban metabolism: the case of Mexico City. Journal of Political Ecology 22: 98-114.

[44] Dinarès M., 2014. Urban Metabolism: A review of recent literature on the subject. Documents d'Anàlisi Geogràfica 2014, vol. 60/3 551-571.

[45] Domenech E., Mallet C., 2014. Change Detection in High resolution land use/land cover geodatabases (at object level). EuroSDR official publication No.64. April 2014.

[46] Duan G., Gong H., Zhao W., Tang X., Chen B., 2013. An index based approach on high resolution images. In Proc. of the International Symposium on Satellite Mapping Technology and Application (ISSMTA2013), 2013. November 6-8, 2013 Nanjing, Jiangsu, China.

[47] Duinker P.N., Greig L.A., 2007.Scenario analysis in environmental impact assessment: improving explorations of the future. Environmental Impact Assessment Review, 27 (3) (2007), pp. 206–219.

[48] Eilering J.A.M., Vermeulen W.J.V.,2004. Eco-industrial parks: toward industrial symbiosis and utility sharing in practice. Progress in Industrial Ecology 2004;1(1/2/3): 245-70.

[49] Fath B.D., Patten B.C., 1999. Review of the foundations of network environ analysis. Ecosystems 1999;2:167–79.

[50] Fearnside P.M., Barbosa R.I., 1998. Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. Forest Ecology and Management 108(1-2): 147-166.

[51] Fearnside P.M., Barbosa R.I., 1998. Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. Forest Ecology and Management Volume 108, Issues 1–2, 20 August 1998, Pages 147–166

[52] Ferretti V., Comino E., 2015. An integrated framework to assess complex cultural and natural heritage systems with Multi-Attribute Value Theory. Journal of Cultural Heritage 16(5) · February 2015 DOI: 10.1016/j.culher.2015.01.007.

[53] Finlayson G. D., Hordley S. D., Cheng Lu, Drew M. S., 2006. On the Removal of Shadows From Images. IEEE Transactions on Pattern Analysis and Machine Intelligence 28 (1), 59-68.

[54] Folke C., Jansson A., Larsson J., Costanza R., 1997. Ecosystem appropriation by cities. Ambio, 167-172.

[fonseca] Fonseca C.M., Fleming P.J., 1993. Genetic Algorithms for Multiob jective Optimization: Formulation, Discussion and Generalization. ICGA 93, 416-423.

[56] Food and Agriculture Organization, 2003. World agriculture: towards 2015–2030. An FAO Perspective, Rome.

[57] Fusiello A., Maset E., Crosilla F., 2013. Reliable exterior orientation by a robust anisotropic orthogonal Procrustes Algorithm. Int. Arch. of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XL-5/W1, pp. 81-87.

[FVG] FVG region, 2011. Piano di azione regionale: di cui all'art.8 della legge regionale 16/2007. Allegato alla delibera 2271 del 24 Novembre 2011.

[59] Galik C., Mobley M., Richter D., 2009. A virtual "field test" of forest management carbon offset protocols: the influence of accounting. Mitig Adapt Strat Glob Chang 14:677–690.

[60] Garro V., Crosilla F., Fusiello A., 2012. Solving the PnP Problem with Anisotropic Orthogonal Procrustes Analysis. In 3dimpvt, pp. 262-269.

[61] Geneletti D., 2004. A GIS-based decision support system to identify nature conservation priorities in an alpine valley. Land Use Policy 21 (2004) 149–160.

[62] Gil J., Duarte J.P., 2013. Tools for evaluating the sustainability of urban design: a review. Proceedings of the Institution of Civil Engineers Urban Design and Planning 166 December 2013 Issue DP6 Pages 311–325 http://dx.doi.org/10.1680/udap.11.00048.

[63] Girardet H., 1992. The Gaia Atlas of cities: new directions for sustainable urban living. London: Gaia Books Ltd.

[64] Girardet H., 1999. Creating Sustainable Cities. Schumacher Briefings.

[65] Gower J.C., Dijksterhius G.B., 2004. Procrustes problems. Oxford University press 2004.

[66] González A., Donnelly A., Jones M., Klostermann J., Groot A., Breil M., 2011. Community of practice approach to developing urban sustainability indicators. Journal of Environmental Assessment Policy and Management, 13, 1–27.

[67] Golubiewski N., 2012. Is there a metabolism of an urban ecosystem? An ecological critique. Ambio, 41, 751–764.

[68] Grimm N.B., Faeth S.H., Golubiewski N.E., Redman C.L., Wu J., Bai X., Briggs J.M., 2008. Global change and the ecology of cities. Science 319: 756–60.

[69] Gromyko M., Shevlakov A., 2004. Classification Analysis of LANDSAT Images of Mixed Coniferous and Deciduous Riparian Forest in Nature Conservation Zone Using GRASS/PostGIS Link. Proceedings of the FOSS/GRASS Users Conference – Bangkok, Thailand, 12–14 September 2004.

[Guo] Guo L.B., Gifford R.M., 2002. Soil carbon stocks and land use change: a meta analysis. Global Change Biology 8: 345- 360.

[71] Haberl H., Erb K.-H., Krausmann F., 2001. How to calculate and interpret ecological footprints for long periods of time: the case of Austria 1926-1995. [doi: DOI: 10.1016/S0921-8009(01)00152-5]. Ecological Economics, 38(1), 25-45.

[72] Hallsmith G., 2007. The Key to Sustainable Cities; Meeting Human Needs, Transforming Community Systems, Canada: New Society Publishers

[73] Hendriks C., Obernosterer R., Müller D., Kytzia S., Baccini P., Brunner P. H., 2000. Material Flow Analysis: a tool to support environmental policy decision making. Case studies on the city of Vienna and the Swiss lowlands. Local Environment: The International Journal of Justice and Sustainability, 5(3), 311-328.

[Hills] Hill M.J, Braaten R, Veitch S.M, Lees B.G, Sharma S., 2004. Multi-Criteria decision analysis in spatial decision support: the ASSESS Analytic Hierarchy Process and the role of quantitative methods and spatially explicit analysis. Environmental Modelling and Software 20: 955–976.

[75] Holsapple C., Whinston A., 1996. Decision support systems: A knowledge-based approach. St. Paul, MN: West.

[76] Huang S., 1998. Urban ecosystems, energetic hierarchies, and ecological economics of Taipei metropolis. Journal of Environmental Management 52, 39-51.

[77] Huang S.L., Hsu W.L., 2003. Materials flow analysis and energy evaluation of Taipei's urban construction. Landscape and Urban Planning 63 (2), 61-74

[78] Huang S., Kao W., Lee C., 2007. Energetic mechanisms and development of an urban landscape system. Ecol. Model. 201, 495-506.

[79] Huang Y., Bird R., Heidrich O., 2009. Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. Journal of Cleaner Production, 17(2), 283-296.

[80] Huang S.L., Chen C.W., 2009. Urbanization and Socioeconomic Metabolism in Taipei. Journal of Industrial Ecology, 13(1), 75-93.

[81] Huang Q., Zheng X., Hu Y., 2015. Analysis of Land-Use Emergy Indicators Based on Urban Metabolism: A Case Study for Beijing. Sustainability 2015, 7, 7473-7491; doi:10.3390/su7067473.

[IPCC] IPCC, 2000. IPCC Special report emissions scenarios. Published for the Intergovernmental Panel on Climate Change.

[83] Jensen J.O., Elle M., 2007. Exploring the use of tools for urban sustainability in European cities. Indoor and Built Environment 16(3): 235-247.

[84] Jesinghaus J., 1999. Indicators for Decision Making, European Commission. European Commission, Ispra, http://esl.jrc.it/envind/idm/idm_e_.htm.

[85] Jørgensen S.E., Fath B.D., Bastianoni S., Marques J.C., Muller F., Nielsen S., Patten B.C., Tiezzi E., Ulanowicz R.E., 2007. A new ecology: Systems perspective. Amsterdam: Elsevier, 2007.

[kalabande] Kalbande D.R., Thampi G.T., 2009. Multi-attribute and Multi-criteria Decision Making Model for technology selection using fuzzy logic. TECHNIA International Journal of Computing Science and Communication Technologies, VOL. 2, NO. 1, July 2009. (ISSN 0974-3375).

[87] Kane M., Erickson J.D., 2007. Urban Metabolism and Payment for Ecosystem Services: History and Policy Analysis of the New York City Water Supply. Advances in the Economics of Environmental Resources. January 2007.

[88] Keen P.G.W., 1980. Decision support systems: A research perspective. Data Base, 12 (1/2), 15-25.

[89] Keenan P., 1997. Using a GIS as a DSS Generator, University College Dublin, URL: http://mis.ucd.ie/staff/pkeenan/gis_as_a_dss.html.

[90] Kennedy C.A., Cuddihy J., Engel Yan J., 2007. The changing metabolism of cities. Journal of Industrial Ecology 2007 (11), 43-59.

[91] Kennedy C., 2010. Urban metabolism: Metrics, applications and a framework for research. University of Toronto.

[92] Kennedy C., Pincetl S., Bunje P., 2011. The study of urban metabolism and its applications to urban planning and design. Environmental Pollution 159 (2011) 1965-1973.

[93] Kennedy C., Stewart I.D., Ibrahim N., Facchini A., Mele R., 2014. Developing a multi-layered indicator set for urban metabolism studies in megacities. Ecol. Indic. 47, 7-15.

[94] Kirschbaum M.U.F., 2003. Can trees buy time? An assessment of the role of vegetation sinks as part of the global carbon cycle. Climatic Change 58: 47-71, 2003.

[95] Lal R., 2004. Soil carbon sequestration to mitigate climate change. Geoderma 123 (2004) 1-22.

[96] Li H., Zhang L., Shen H., 2014. An Adaptive Nonlocal Regularized Shadow Removal Method for Aerial Remote Sensing Images. IEEE Transaction on Geoscience and Remote Sensing, Vol. 50, No. 9, September 2012.

[97] Liang S., Wang C., Zhang T., 2010. An improved input–output model for energy analysis: a case study of Suzhou. Ecol Econ 2010;69(9):1805-13.

[98] Liang S., Zhang T., 2011. Urban Metabolism in China Achieving Dematerialization and Decarbonization in Suzhou. Journal of Industrial Ecology Volume 15, Number 3.

[99] Lorenzi L., Melgani F., Mercier G., 2012. A Complete Processing Chain for Shadow Detection and Reconstruction in VHR Images. IEEE Transaction on Geoscience and Remote Sensing, Vol. 50, No. 9, September 2012.

[100] Lorenzi L., Melgani F., Mercier G., Bazi Y., 2013. Assessing the Reconstructability of Shadow Areas in VHR Images. IEEE Transactions on Geoscience and Remote Sensing, pp: 2863 - 2873 Volume: 51, Issue: 5, May 2013.

[101] Lu Y., Chen B., Hayat T., Alsaedi A., 2015. Communal carbon metabolism: methodology and case study. Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.10.137.

[102] Ma H., Qin Q., Shen X., 2008. Shadow segmentation and compensation in high resolution satellite images. Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International. Vol. 2. IEEE, 2008.

[Mahali] Malhi Y., Baldocchi D.D., Jarvis P.G., 1999. The carbon balance of tropical, temperate and boreal forests. Plan, cell, environment (1999) 22, 715-740.

[104] Makarau A., Richter R., Muller R., Reinartz P., 2011. Adaptive shadow detection using a blackbody radiator model. IEEE Transactions on Geoscience and Remote Sensing. June 2011, Vol. 49 Issue 6, p. 2049, 11 p.

[105] Mahfouz A., Shea J., Arisha A., 2011. Simulation based optimization model for the lean assessment in SME: a case study. In Proceedings of the Winter Simulation Conference (WSC '11), pp. 2403-2413, Phoenix, Ariz, USA, December 2011.

[106] Mellino S., Rip M., Zucaro A., Ulgiati S., 2013. An emergy GIS approach to the evaluation of renewable resource flows: a case study of Campania Region, Italy. Ecol. Model. 271, 103-112.

[107] Minx J.C., Creutzig F., Medinger V., Ziegler T., Owen A., Baiocchi G., 2011. Developing a Prgamatic Approach to Assess Urban Metabolism in Europe´: A Report to the Environment Agency prepared by Technische Universität Berlin and Stockholm Environment Institute, Climatecon Working Paper 01/2011, Technische Universität Berlin.

[108] Montagnini F., Nair P.K.R., 2004. Carbon sequestration: An underexploited environmental benefit of agroforestry systems. Agroforestry Systems 61: pp. 281-295.

[109] Movia A., Beinat A., Crosilla F., 2015. Comparison of unsupervised vegetation classification methods from VHR images after shadows removal by innovative algorithms. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 40 (7W3), pp.1269.

[110] Movia A., Beinat A., Crosilla F., 2016. Shadow detection and removal in RGB VHR images for land use unsupervised classification. ISPRS Journal of Photogrammetry and Remote Sensing. Vol. 119, September 2016, Pages 485–495. http://dx.doi.org/10.1016/j.isprsjprs.2016.05.004.

[Movia 2016] Movia A., Beinat A., Sandri T., 2016 Land use classification from VHR aerial images using invariant colour components and texture. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives 41, pp.311. 2016.

[112] Newman P.W.G., 1999. Sustainability and cities: extending the metabolism model. Landscape and Urban Planning, 44(4), 219-226. doi: DOI: 10.1016/S0169-2046(99)00009-2.

[113] Ngo N.S., Pataki D.E., 2008. The energy and mass balance of Los Angeles County. Urban Ecosystems 11, 121-139.

[114] Niza S., Rosado L., Ferrão P., 2009. Urban Metabolism. Journal of Industrial Ecology, 13: 384–405. doi:10.1111/j.1530-9290.2009.00130.x.

[115] Noorollahi Y., Jokar M.A., Kalhor A., 2016. Using artificial neural networks for temporal and spatial wind speed forecasting in Iran. Energy Conversion and Management. Vol. 115 p. 17–25. DOI: 10.1016/j.enconman.2016.02.041.

[116] Odum E., 1989. Ecology and our endangered life-support systems. Sinauer Associates, Sunderland, MA (1989).

[PAES] Comune di Tavagnacco. Piano d'Azione per l'Energia Sostenibile (PAES). Thomas & Greenman.

[Parnell] Parnell G.S., Hughes D.W., Burk R.C., Nunn L.R., 2002. Invited Review—Survey of Value Focused Thinking: Applications, Research Developments and Areas for Future Research. Journal of Multi-Criteria Decision Analysis 20(1-2) April 2013 DOI: 10.1002/mcda.1483

[119] Parshall L., Gurney K., Hammer S.A., Mendoza D., Zhou Y., Geethakumar S., 2010. Modeling energy consumption and CO_2 emissions at the urban scale: Methodological challenges and insights from the United States. Volume 38, Issue 9, September 2010, Pages 4765-4782.

[120] Pataki D.E., 2010. Integrating ecosystem services into the urban metabolism framework. University of California.

[pelizaro] Pelizaro C., McDonald D., 2008. Spatial (GIS-based) Decision Support System for the Westernport region. Applied GIS, Volume 2, Number 3, 2006. Monash University Epress.

[122] Pincetl S., Bunje P.M.E., 2009. Potential Targets and Benefits for Sustainable Communities Research, Development, and Demonstration Funded by the PIER Program, prepared for California Energy Commission, UCLA Institute of the Environment.

[123] Pincetl S., Bunje P., Holmes T., 2012. An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. Landscape and Urban Planning, 107, 193–202.

[124] Pohekar S., Ramachandran M., 2004. Application of multi-criteria decision making to sustainable energy planning. Renewable and Sustainable Energy Reviews, 365-381.

[125] Pope J., Annandale D., Morrison-Saunders A., 2004. Conceptualising sustainability assessment. Environmental Impact Assessment Review 24(6): 595–616.

[126] Post W.M., Know K.C., 2000. Soil Carbon Sequestration and Land-Use Change: Processes and Potential. Global Change Biology (2000) 6, pp. 317–328.

[127] Power D.J., 2008. Decision Support Systems: A Historical Overview. In Burstein, & Holsapple, Handbook on Decision Support System 1 (p. 121 - 140). Springer.

[128] Prato T., 2008. Conceptual framework for assessment and management of ecosystem impacts of climate change. Ecol. Complex. 5, 329e338.

[129] Rayed C.A., 2012. Using GIS for Modeling a Spatial DSS for Industrial Pollution in Egypt. American Journal of Geographic Information System p-ISSN: 2163-1131 e-ISSN: 2163-114X 2012; 1(4): 100-104 doi: 10.5923/j.ajgis.20120104.01.

[130] Rapoport E., 2011. Interdisciplinary perspectives on Urban Metabolism. A review of the literature. UCL Environmental Institute working paper. Development planning unit, UCL.

[131] Rebitzer G., Ekvall T., Frischknecht R., Hunkeler D., Norris G., Rydberg T., Schmidt W.-P., Suh S., Weidema B.P., Pennington D.W., 2004. Life cycle assessment. Part 1: Framework, goal and scope definition, inventory analysis, and applications. Environment International, Vol. 30, pp. 701-720.

[rigoni] Rigoni E., Poles S., 2005. NBI and MOGA-II, two complementary algorithms for Multi-Objective optimizations. Dagstuhl Seminar Proceedings 04461 Practical Approaches to Multi-Objective Optimization http://drops.dagstuhl.de/opus/volltexte/2005/272.

[133] Rotmans J.M., Van Asselt C., Anastasi S., Greeuw J., Mellors S., Peters D., Rothman N., Rijkens., 2000. Visions for a sustainable Europe. Futures 32: 809-831.

[134] Sahely H., Dudding S., Kennedy C., 2003. Estimating the urban metabolism of Canadian cities: Greater Toronto Area case study. Canadian Journal of Civil Engineering, 30(2), 468-483.

[135] Schulp C.J.E., Alkemade R., Goldewijk K.K., Petz K., 2012. Mapping ecosystem functions and services in Eastern Europe using global-scale data sets. Int J Biodivers Sci Ecosyst Serv Manag 8:37-41.

[136] Shim J.P., Warkentin M., Courtney J.F., Power D.J., Sharda R., Carlsson C., 2002. Past, present, and future of decision support technology. Decision Support Systems, 33, 111–126.

[137] Smith P., Martino D., Cai Z., Gwary D., Janzen H., Kumar P., ... , Towprayoon S., 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agriculture, Ecosystems & Environment, 118(1), pp. 6-28.

[138] Smith P., Morrison W.I., 2006. Simulating the urban economy: experiments with input–output techniques. Routledge 2006.

[139] Sugumaran R., Degroote J., 2011. Spatial decision support systems. Principles and Practice. Boca Raton: Taylor & Francis.

[140] Thomas M.R., 2002. A GIS-based decision supportsystem for brownfield redevelopment. Landscape and Urban Planning 58, 7-23.

[141] Thomas A.M., Cathcart J. M., 2008. Adaptive Spatial Sampling Schemes for the Detection of Minefields in Hyperspectral Imagery. in Proc. of SPIE Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XIII 6953(28).

[142] Timmer M.P., 2012. The World Input–Output Database (WIOD): Contents, Sources and Methods. WIOD Working Paper Number 10; 2012.

[143] Tsai V.J.D., 2006. A comparative Study of Shadow Compensation of Color Aerial Images in Invariant Color Models. IEEE Transaction on Geoscience and Remote Sensing, Vol. 44, No. 6, June 2006.

[144] Udo de Haes H.A., Heijungs R., Suh S., Huppes G., 2004. Three strategies to overcome the limitations of Life-Cycle Assessment. Massachusetts Institute of Technology and Yale University, Journal of Industrial Ecology, Vol. 8, No. 3, pp. 19-32.

[145] Ulanowicz R.E., 2011. Quantitative Methods for Ecological Network Analysis and Its Application to Coastal Ecosystems. Treatise on Estuarine and Coastal Science, 2011, Vol.9, 35-57, DOI: 10.1016/B978-0-12-374711-2.00904-9.

[146] Van Berkel R., Fujita T., Hashimoto S., Fuji S., 2009. Quantitative assessment of urban and industrial symbiosis in Kawasaki (Japan). Environmental Science and Technology 43(5): 1271–1281.

[147] Vande Weghe J., Kennedy C., 2007. A spatial analysis of residential greenhouse gas emissions in the Toronto census metropolitan area. J. Ind. Ecol. 2007, 11 (2), 133–144.

[148] Villarroel-Walker R., Beck M.B., 2012. Understanding the metabolism of urban–rural ecosystems: A multi-sectoral systems analysis. Urban Ecosystems, http://dx.doi.org/10.1007/s11252-012-0241-8.

[149] Vinodh S., Balaji S.R., 2011. "Fuzzy logic based leanness assessment and its decision support system," International Journal of Production Research, vol. 49, no. 13, pp. 4027–4041.

[150] Voskampa I.M., Spiller M., Stremke S., Bregt A.K., Vreugdenhil C., Rijnaarts H.H.M., 2016. Space-time information analysis for resource-conscious urban planning and design: A stakeholder based identification of urban metabolism data gaps. Resources, Conservation and Recycling. *In press.*

[151] Xu M., Zhang T., Allenby B., 2008. How much will China weigh? Perspectives from consumption structure and technology development. Environmental Science & Technology 42, 4022–4028.

[152] Xu Y., Zhang T., 2007. Regional material flow analysis model based on threedimensional physical input–output table. Journal of Tsinghua University (Science & Technology) 47, 356–360.

[153] Yang D. W., Kao W., Tze M., Zhang G. Q., Zhang, N. Y., 2014. Evaluating spatiotemporal differences and sustainability of Xiamen urban metabolism using emergy synthesis. Ecol. Modell. 2014, 272, 40—48.

[154] Yuan H., Shi C. F., Xiao S., 2009. An Automated Artificial Neural Network System for Land Use/Land Cover Classification from Landsat TM Imagery. Remote Sens. 2009, 1, pp. 243-265; doi: 10.3390/rs1030243.

[155] Wackernagel M., Rees W.E., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. Gabriola Press New Society Publishing, B.C.

[156] Warren-Rhodes K., Koenig A., 2001. Escalating trends in the Urban Metabolism of Hong Kong_1971-1997. Ambio, 30(7), 429-438.

[157] Wolman A., 1965. The metabolism of cities. Scientific American 213 (3), 179-190.

[158] Zhang, Y., Zhao, Y. W., Yang, Z. F., Chen, B., & Chen, G. Q., 2009. Measurement and evaluation of the metabolic capacity of an urban ecosystem. [doi: DOI: 10.1016/j.cnsns.2008.03.017]. Communications in Nonlinear Science and Numerical Simulation, 14(4), 1758-1765.

[159] Zhang Y., Xia L., Xiang W., 2014. Analyzing spatial patterns of urban carbon tabolism: a case study in Beijing, China. Landsc. Urban Plan. 130, 184-200.

[160] Zhang Y., Yang Z., Yu X., 2015. Urban Metabolism: A Review of Current Knowledge and Directions for Future Study. Environ. Sci. Technol., 49 (2015), pp. 11247–11263 http://dx.doi.org/10.1021/acs.est.5b03060.

[161] Zhao R., Huang X., Zhong T., Liu Y., Chuai X., 2014. Carbon flow of urban system and its policy implications: the case of Nanjing. Renew. Sustain. Energy Rev. 33, 589-601.

[162] Zucchetto J., 1975. Energy, economic theory and mathematical models for combining the systems of man and nature. Case study, the urban region of Miami. Ecological Modelling 1, 241-268.